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OPERATIONAL ROLES, AIRCREW SYSTEMS AND HUMAN FACTORS IN FUTURE HIGH PERFORMANCE AIRCRAFT

Edited by

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Papers presented at the Aerospace Medical Panel's Specialists' Meeting held in Lisbon, Portugal, 22–26 October 1979.

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SUMMARY

This conference, held in Lisbon, Portugal, 22-26 October 1979, considered several aspects of high performance aircraft currently in the NATO inventory so that the problems associated with the human operator in future high performance aircraft can be more clearly delineated and prepared for. The three aircraft discussed were the F-16, Mirage 2000, and Tornado. The operational roles, aircrew systems, and human factors aspects of these aircraft were considered in detail by experts from the United Kingdom, United States, and France. Each expert was selected and invited to prepare a paper for presentation. The papers were not reviewed or edited by the Aerospace Medical Panel prior to presentation.

The plan for the session was to have presentations of the operational roles of the aircraft first in order to set the stage for consideration of the advanced aircrew systems in these aircraft and thence to discussion of the human factors aspects of operating these aircraft. This last aspect is of special significance to the Aerospace Medical Panel since the human operator problems of the current aircraft are, in all probability, the types of problems, but magnified, to be encountered in future high performance aircraft. Thus, some direction is indicated as to what kinds of research need to be performed in order to meet the demands made on the operator in new aircraft.

PREFACE

The introduction of new high performance aircraft into the NATO community will impose additional physical, physiological, and psychological demands on the aircrew. Weapon systems are no more effective than their human operators' capabilities; thus, the system is merely an extension of the operator's sensory, muscular, and cognitive capacities in responding to all of the mission stresses. To ensure accomplishment of operational missions, the relationship between man and the system he operates must be as compatible as possible. The NATO aerospace medical community must be aware of the performance, systems, and operational characteristics of the current high performance aircraft in relation to the human operator's physiological, cognitive, psychomotor, and perceptual capabilities. Identification of biotechnical research needs is critical and must be underway as soon as possible so that appropriate medical selection, training, and assignment criteria may be established for future aircraft, as well as development of additional protective equipment and systems.

In order to provide a background for the above requirements, the Long Range Planning Subcommittee conceived a symposium which would consider the operational roles, aircrew systems, and human factors aspects of three advanced aircraft: The F-16, Mirage 2000, and Tornado. The proposed session was presented to the Aerospace Medical Panel at the 34th Annual Business Meeting in 1977 and accepted for the program of the 36th Annual Meeting in Lisbon, Portugal, 22-26 October 1979. Nine detailed presentations were planned, three on each of the aircraft.

The presentations were of 30 minutes duration and a discussion period was planned at the end of each three papers. However, only one discussion period was held, at the end of the session. The discussions have been edited by the Session Organizer based primarily on tape recordings and notes, and they were not reviewed by the discussants. Because of technical difficulties encountered in the recording system, the discussions are not complete. However, as much of the discussion is included as was possible under the circumstances.

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Technical Evaluation Report

by

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Introduction

In response to a proposal presented by the Long Range Planning Subcommittee to the Aerospace Medical Panel, a scientific session was planned for the 36th Panel Business Meeting and Specialists Meeting held in Lisbon, Portugal, 22-26 October 1979. The session was titled "Operational Roles, Aircrew Systems and Human Factors in Future High Performance Aircraft." Invitations were extended to nine experts from France, the United States, and the United Kingdom to present papers of 30-minutes duration. One day was devoted to this session.

The session was logically divided into three subsessions, each with three speakers and a chairman. The plan was to have a 30-minute discussion period at the end of each subsession. However, because of overruns only one discussion period was held at the end of the session. The subsessions were concerned with the three aspects of advanced aircraft indicated in the title; namely, operational roles, aircrew systems, and human factors. The three examples of high performance aircraft currently in the NATO inventory which were discussed were the F-16, the Mirage 2000, and the Tornado. These were considered to be prime examples of the trend in advanced weapons systems and would be indicative of future human operator requirements and problems.

Summary of Communications

The authors were given freedom in deciding the content of their papers within the general constraint of the three themes of the symposium. The first three speakers set the stage, so to speak, for the remaining speakers by describing in some detail the operational roles of the three aircraft and illustrating these roles by showing types of missions which might be flown and the weapons which might be used during those missions.

The three papers on aircrew systems were quite varied in content. Content varied from a consideration of information transfer of essentially a single complex system (missile fire control) (USA) to a discussion of many systems (cabin environmental, g-protection, oxygen escape, restraint systems, etc.) (UK), to a discussion of the weapon systems involved in various mission scenarios (FR). This subsession did not therefore give a uniform picture of the aircrew systems of the three aircraft.

The last set of three papers addressed human factors aspects of these advanced aircraft. Again, presentations varied from a consideration of the interplay of human factors technology with system design during the concept phase of development (USA) to a discussion of effects of acceleration, high altitude, and mental workload required during various missions (FR) to a consideration of crew comfort and those factors which affect comfort, to physiological aspects, workload, psychological aspects, automation and spatial disorientation (UK).

Conclusions and Recommendations

The objective of this symposium was somewhat of a departure from other technical meetings sponsored by the Aerospace Medical Panel. Specific weapon systems currently in the NATO inventory were discussed with the aim of describing current aircrew roles and problems and thereby pointing out potential problems in future high performance aircraft It appears to me that this type of meeting is exceptionally valuable because it is oriented to the future and does not, as we are so often inclined, concentrate on current problems without regard to what problems will occur in a few years. That philosophy encourages maintenance of a reactive role and does not stimulate a more positive catalyst role for the NATO community. We must anticipate the future and plan our research priorities accordingly.

An additional dividend of this type of meeting was that it involved operational personnel as well as the scientific community. The knowledge and experiences of operational people add another dimension to our ability to determine the human problems associated with advanced weapon systems. The Aerospace Medical Panel now has a firm grasp of the complex roles, systems, and aircrew aspects of the three weapon systems discussed.

It would be my recommendation that another symposium, patterned much the same as this one, be convened in three to five years. The objective of that symposium would be to build on the current one but with the additional aim of delineating the problems which would be associated with future aircraft such as control contoured vehicles. Three to six experts would be invited to present papers, and a panel composed of the speakers as well as additional experts would round out the session with a discussion of the direction research should take in order to anticipate and meet the requirements of future aircraft. Experts from other AGARD panels should be invited to sit on the discussion panel.

KEYNOTE ADDRESS

by

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On behalf of the Chief of Staff, Portuguese Air Force, it is my great pleasure to greet the members of the Aerospace Medical Panel on the occasion of its meeting for the second time in Portugal.

It is indeed a great privilege for us to host once again this meeting of leading personalities of NATO in the fields of science and technology relating to aerospace. We hope that your work will be fruitful and, simultaneously, that you will be afforded the opportunity of enjoying some of the natural beauties of my country, and of meeting some of its people whose hospitality and friendliness I always like to emphasize.

The short words of welcome I am honoured to address to you at this opening ceremony have, as a starting point, a brief comment on the circumstances that set the framing for the Portuguese Armed Forces.

Portugal, the oldest state-nation of Europe, is going nowadays through a very difficult period of its already long life as an independent country. At this historical moment, on its shoulders fell, simultaneously, the consequences of a grave crisis in the world economy and the effects of a sudden and disordered withdrawal from territories in the African continent which we have for centuries, colonized, administered, developed, explored and loved.

The unexpected drying up of preferential sources of raw materials and food products, the closing of complementary and privileged markets, and the return of over half a million refugees (just to mention the most important events) were altogether a severe blow for the faint-hearted Portuguese economy, badly shaken already by thirteen years of erosive guerrilla warfare with no military solution. The progressive rise in oil prices worldwide not only hampered the expected economic recovery, but contributed to an aggravation of the situation.

As a corollary to this and also why not mention it a certain tendency of the Portuguese people to the anarchic populism, the internal order of the country was badly degraded and, with it, the production output. In parallel, a profound crisis of national identity developed as well, more profound even than the economic and political crisis, which will take a longer time to overcome. Confused and disoriented, the Portuguese question themselves about the "collective sense of their destiny", and search for the "accurate definition of their own space among the other nations".

The times we are living in are, therefore, times of crisis: political, economical and of national identity.

In this national frame, of course, live the Armed Forces.

The effect of the crisis on them is obvious.

During the past stage of greater social instability, the armed forces lived through moments of almost total anarchy, during which they suffered a profound split and were used as a plaything in the hands of the various political groups. It was a rather troubled period resulting from the political inexperience and ingenuousness of the servicemen.

However, recovered after having been caught by surprise, when the fundamental values from which they stem naturally emerged again to definitely muffle down the false myths and Utopian demagogism, they managed to free themselves from the mess where blindly and apathetically they had fallen.

Today, all servicemen "trustees of tamed violence" although aware of the importance of their role in the nation's political life, wish to resume the classic role of watching out for the national security, within the framework of the established democratic rule and in total subordination to the legitimate political power, while responsible for determining the time and place where force shall be used.

I expect that the Portuguese Armed Forces will never again become an instrument of political forces, other than the ones which represent the will of the people and the national interests.

They stand watch for the deceiving mermaids song, for the seducing false pleas, no matter where they come from, because they shatter the unity so peculiar to the military institution, and indispensable as a solid foundation to its strength

At this time, I believe one can make applicable to the Portuguese Armed Forces the old popular saying. "a burnt child dreads the fire".

In what concerns their operational capability, the Armed Forces are obviously affected by the severe constraints of our economy, and also by a clear anti-military social attitude based mainly on economic but also on political considerations. In our particular case, there are still individuals and/or political groups interested in, or determined to foment instability within the Armed Forces, for well-known but not publicly stated reasons. Others accuse the Armed Forces of uselessly consuming national resources badly needed in projects of economic development. And there are others who defend, as a matter of convenience, the existence of the Armed Forces, using them as scapegoats to be blamed for anything that goes wrong in the political and economic fields, and also for their own shortcomings and unfitness.

The development of a situation like this, I believe, is by no means exclusive to Portugal. Most likely, it took place as well in other countries that lived through periods of similar social turmoil, economic crisis or stages of development

Although the political leadership has, thus far, avoided getting involved with the definition of the national defense organization and policy, so to clarify the image and role of the Armed Forces within the Portuguese society of today, mainly because such a definition means assuming responsibility for providing them with the material means necessary to carry the assigned mission, one can nevertheless say that the Portuguese Armed Forces deduced mission is relatively evident, at least on its qualitative aspects.

In so far as the Air Force is concerned, its available resources ... the ones it tries to obtain, under the circumstances, represent a minimum requirement for carrying out the tasks which the Portuguese Constitution broadly defines, for fulfilling international commitments, or simply to enable its routine training in order to keep its valuable experience acquired in the operational environment.

Within this line of thinking, the Air Force does not have, at the present, either the capability to operate high-performance aircraft, such as F-16, Mirage 2000 or Tornado, or the hope to acquire it in the short term.

Neither is Portugal politically engaged in any sort of armaments race, nor do we the military people wish to deviate to the armaments field the scarce economic resources, so badly required to satisfy our people's basic needs, through its investment in projects of economic and social development

On the other hand, we consider it essential to strike a balance between the sophistication of the air assets in our inventory and the technological development of the country, thus recognizing that, to have aircraft of such high performance whose maintenance can't be, to a minimum degree, supported by the national industry, is not of national interest. We admit, however, as beneficial, the existence of a certain technological gap to act as a challenge, and to stimulate progress and transfer of "know-how".

The Air Force is, therefore, at this time, orientating its main efforts to the optimization of the human and material resources already available, to the development of the individual capabilities of its men, and to improving its decision making process.

At the same time, in the technical and scientific fields, it tries to be in touch with the most recently produced technology or scientific breakthroughs.

Therefore, the Portuguese Air Force, although operating an airplane generation obsolete by the standards of the most developed countries, but nevertheless still fit to carry out its mission in the national framework, permanently struggles to keep itself up-to-date with the development and operational use of high-performance airplanes and related problems.

This line of thought justifies our deep interest and great satisfaction in hosting this 36th Panel Business and Specialist Meeting here in Portugal.

Our Air Force medical doctors, who integrate with the NATO Aerospace medical community, will have the opportunity to learn about the operational performances of the most advanced airplanes in being, or projected to be used in Europe, and also about the problems related to the selection, training and required capacity of their crews to carry out missions under heavy mental and physical stress. They will, for sure, broaden their views and understanding of the problems that will affect our crews in the future.

Some of our most qualified pilots also have the opportunity of coming to this meeting. Like all pilots they are always eager to fly higher and faster. They will, therefore, have the possibility to listen to the interesting communications you are going to make, according to their proposed titles, and to anticipate some thinking about the problems of the operational use of high-performance airplanes which, some day, they may have the chance to fly themselves. They can start getting adjusted to the restrictions imposed by a heavily hostile environment. flying faster, yes, but definitely much lower.

When the time comes to do it, a solution may have been found for many of today's problems, as a consequence of the studies developed, and the exchange of scientific and technological information, an exchange which is made easier and encouraged by meetings like the one you are going to have here.

From our side, as host nation, we will retain a modest feeling of participation, if not through a direct and productive contribution to the studies to improve performance of men and weapons in an hostile environment, at least through the administrative arrangement of this meeting, through our presence here and our great interest in the subject, and certainly with our most warm welcome to all of you. This feeling of participation is, in its simplicity, useful from a psychological point of view. It gives us the impression of having moved a step forward - no matter how little it may be towards the more developed nations of the North, a step that may not be long enough to narrow the gap, but will be big enough to prevent the gap from widening.

I suppose, that, in fact, one can consider your coming to us, within the perspective of the North-South approach.

We all are aware of the disparity between the highly industrialized nations and the less developed countries - the more seriously affected by the world economic crisis - and we all know how it tends to aggravate itself and to become a source of tension and conflicts.

Nowadays, in opposition to the until recently dominant way of thinking, the long-term development - a strategic objective in every country is considered to be far more dependent upon cultural, social and political changes than upon a wider availability of material resources.

Portugal underwent already and still is undergoing changes of that nature. The respective fruits will be picked eventually, but only in the long term.

In this picture of the Portuguese situation I have tried to draw for you, using colors somewhat covered by heavy shades, the Portuguese Air Force, with the energy and enthusiasm of its youth, keeping itself strongly motivated and internally cohesive. In spite of the difficulties, setbacks and not too good perspectives, the Air Force has found in itself the necessary stamina to develop its operational capacity, bearing in mind that progress is more dependent upon its own initiative than upon outside support.

The Organization of which you are distinguished members is a source of stimulus and I believe it can provide our own human resources with incentive, guidance and support to their endeavours of developing adequate investigation programs, no matter how limited our available means may be.

After all, no matter how big, the available means are always limited.

As I extend to all and each one of you, distinguished representatives of NATO member countries, a specially warm welcome to Lisbon, on behalf of the Chief-of-Staff of the Portuguese Air Force, I also wish that you enjoy your stay in Portugal and after your return to your countries that you may keep a pleasant souvenir of the time you spent with us.

THE OPERATIONAL ROLES OF THE F-16

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SUMMARY

This paper carefully describes the F-16 weapons system from its design features to its cockpit displays and controls. The multirole capacity of the F-16 is illustrated by description of the weapons delivery systems, aircraft performance, and weapons carriage capability. Typical operational missions from NATO bases in F-16 European participating countries over Central and Northern Europe are discussed in detail.

The F-16 is a new generation, single-engine, single-seat, multirole tactical fighter. Several advanced technologies are combined to produce the best pilot-fighter combination possible in an aircraft that is smaller, lighter and simpler than present designs. These technologies attempt to yield an aircraft with far greater maneuverability and combat capability at lower cost.

Figure 1 lists the advanced technologies employed in the F-16. A brief discussion on each of these technologies is contained in the following paragraphs.

The relaxed static longitudinal stability results in range-increasing higher lift to drag ratios at subsonic and supersonic speeds. The nominal center of gravity position for the F-16 is at approximately the 35 percent mean aerodynamic cord. This results in a negative static margin of approximately 10 percent while subsonic and a positive static margin of about 15 percent while supersonic. This feature avoids or minimizes the trim drag of conventional aircraft by creating a useful tail up-load while subsonic and a lower tail down-load at supersonic speeds.

The fly-by-wire flight control system of the F-16 provides a highly reliable, precise, responsive control system which compliments the relaxed stability concept. By fly-by-wire we mean there are no mechanical connections from the pilot's control stick to the control surfaces. The aircraft is controlled by electrons alone. The system incorporates angle of attack and g limiting features which enable the pilot to use the F-16's full maneuver potential without fear of loss of control or structural overload. This quadruplex system achieves high reliability through electrical redundancy. Its response characteristics are easily adapted to changes to the aircraft configuration.

The blended wing-body concept of the F-16 enhances performance, reduces weight and increases body lift at high angles of attack. It helps the aircraft achieve a high ratio of fuel to gross weight which is essential for range and endurance. The transonic drag is also reduced as a result of improved area distributions.

Variable wing camber is provided by the automatic, infinitely variable, leading edge flaps which position to provide the optimum lift to drag ratios over a wide range of flight conditions. They are automatically positioned as a function of Mach number and angle of attack to minimize drag and significantly reduce buffet. They have the same electrical and hydraulic redundancy and the same surface deflection rates as a primary flight control surface. They provide a significant contribution to the longitudinal and directional stability of the F-16. While landing the ailerons are automatically biased down 20 degrees to provide additional wing camber for slower approach speeds.

The forebody strakes move the center of pressure forward increasing fuselage lift. They also introduce a vortex flow field over the fuselage greatly increasing the directional stability at high angles of attack.

The high G cockpit incorporates a 30 degree reclined seat and a raised heel line to increase the pilot's "g" tolerance. The pilot comfort during long cruise missions and during hard maneuvering is phenomenal. As more pilots fly the F-16, I am personally convinced the U.S. Air Force will not produce another fighter without a slope back seat. The cockpit geometry and the unique, one piece bubble canopy and windscreen permit almost unlimited visibility. The conventional canopy bow is located behind the pilot where it blocks less visibility, and people are less likely to hang lights and indicators on it which further reduce forward visibility. The side-stick and arm rest permit the pilot to execute precise maneuvers under high g loads.

The advanced afterburning engine of the F-16 features a high-thrust-to-weight ratio turbofan of the 25,000 pound thrust class. The Pratt & Whitney, F100-PW-100 engine, the same engine that powers the F-15 Eagle, features variable stator blades in the fan compressor, high turbine inlet temperatures with the first stages air cooled, a high pressure ratio, a light weight convergent-divergent nozzle and modular engine components.

The Advanced Digital Avionics system of the F-16 includes a MIL-STD-1553 multiplex bus and digital fire control computer which control act' n of the radar electro-optical display, the head-up display, the multimode pulse-doppler radar, the inertial navigation set, and the stores management set. The Westinghouse radar exploits advanced digital techniques to produce outstanding performance in its air-to-air and air-to-surface modes.

The F-16 as shown in Figure 2 is 14.51 meters long, 5.01 meters high and has a 9.44 meter wing span. It has 300 square feet of wing area. A wing aspect ratio of 3.0. The wing leading edge sweep back angle is 40 degrees. With two missiles, a pilot, full gun and a full load of internal fuel the F-16A weighs 22,600 pounds (10,275 kilograms). With its 25,000 pounds (11,365 kilograms) thrust class engine that yields thrust to weight ratio better than one-to-one at takeoff. The F-16B is a two place fighter/trainer version of the F-16 which is structurally the same as the F-16A. It carries about 1,100 pounds less internal fuel, but it has the same maneuver performance as the F-16A. Both F-16's are designed to 9 g's with a full load of internal fuel. A rugged, safe, durable airframe is assured by a design fatigue life of 8,000 hours.

Figure 3 shows the size comparison of the F-16A with current U.S. fighters. Please note that the basic takeoff weight of the F-4E, F-15A and F-14A are 2.1, 1.9 and 2.6 times that of an F-16 respectively. The internal fuel fraction of the F-16 is 0.30 while that of the F-4E, F-15A and F-14A are 0.25, 0.28, and 0.26 respectively. Note that there is only one engine to consume that fuel in the F-16.

The F-16 cockpit displays and controls are shown in Figure 4. The mission displays and controls occupy the up front area of the cockpit. The displays and controls are designed for head-up and hands-on (the stick and throttle) control of the weapons system. Therefore, it is not necessary to take your eyes off a target to launch a weapon at it.

As depicted in Figure 5 the F-16 will be employed as a multirole fighter. Although originally optimized for air-to-air combat the high thrust to weight ratio and the low wing loading make the F-16 an excellent air-to-surface machine. The U.S. Air Force will use the F-16 as a "swing" aircraft to contribute not only to the air-to-air mission but also for air-to-surface support. The F-16 will replace the multipurpose F-4 Phantom in the U.S. Air Force inventory in the late 1970's and into the 1980's.

As depicted in Figure 6 the F-16 has a multirole weapons delivery capability. For the air-to-air role the F-16 has several weapons delivery modes. A pulse-doppler, look down, clutter free radar is used to search for, detect and track airborne targets. Slightly longer radar detection range can be obtained in look up modes. An automatic, air combat maneuvering, mode is used to automatically lock on to a target in the pilot selected field of view. Dynamic launch zone information and automatic missile track modes are used to employ the AIM-9 heat seeking, "Sidewinder", air intercept missiles. Lead computing optical sight and snapshoot displays on the head-up display are used to employ the General Electric, M-61, Vulcan, 20mm cannon. This gun is capable of firing 6,000 rounds per minute. Energy maneuvering displays are provided on the head-up display to assist the pilot in optimizing aircraft performance during air-to-air combat.

In the air-to-surface role the F-16 has several additional weapons delivery modes. In a visual delivery environment the head-up display, radar, inertial navigation system and fire control computer yield pilot selectable Continuously Computed Impact Point (CCIP), Dive Toss (DTOS), and manual depressed reticle release modes. The ground map modes of the radar are particularly impressive. The inertial navigation system provides automatic cursor placement and automatic antenna tilt for the ground map radar. Expand and doppler beam sharpened ground map modes improve radar resolution. Blind bombing delivery modes of Continuously Computed Release Point (CCRP), Beacon and Low Altitude Drogue Delivery (LADD) are available. Electro-optical guided bombs and missiles like the "Hobo" and "Maverick" are easily and accurately delivered. A laser spot tracker mode is also available for the F-16.

When compared to the multirole F-4E Phantom, the aircraft the F-16 is going to replace in the U.S. Air Force, the F-16 has outstanding performance capabilities. As graphically shown in Figure 7, the F-16 has a 3.0 times the air-to-air combat mission radius and 2.4 times the air-to-surface combat radius of the F-4E. The F-16 uses a lesser turn radius and a shorter time to accelerate from 0.9 Mach to 1.6 Mach at 30,000 feet than the F-4E. The unrefueled ferry range of the F-16 is 1.6 times that of the F-4E.

As shown in Figure 8, the nine external store stations of the F-16 have a total carriage capacity of 15,200 pounds. With full internal fuel, the F-16 can carry 10,500 pounds of external stores. The primary weapons for air-to-air missions are AIM-9 infrared, heat seeking missiles and the rapid fire Vulcan 20mm cannon. For air-to-surface missions, a large variety of guided and unguided weapons, ECM pods and external fuel tanks can be carried on the five air-to-surface hard points.

The doppler beam sharpening mode of a ground map radar is particularly impressive. Shown on Figure 9 is the 10 mile expand, doppler beam sharpened radar picture of the main runway at Edwards AFB, California. The radar cursors are positioned at the north west corner of the intersection of the main runway and the center taxiway. The shorter "south base" runway at Edwards is also seen.

Figure 10 represents a typical air superiority mission radius for NATO in Central and Northern Europe. With takeoffs from representative bases for the European participating governments of The Netherlands, Norway, Denmark and Belgium the F-16 could perform

air combat patrol in the area shown. For this mission the F-16 is loaded with two AIM-9 missiles and two 370-gallon external tanks. The tanks would be dropped when empty. A combat reserve for a Maximum power acceleration from 0.9 Mach to 1.6 Mach, 3 Maximum power sustained 360 degree turns at 1.2 Mach, and 4 Maximum power sustained 360 degree turns at 0.9 Mach is included. A climb to optimum cruise altitude and instrument flight rules landing fuel reserves are also included.

A typical close air support mission over the same area from the same bases is shown in Figure 11. For these missions the F-16 is loaded with two AIM-9 missiles, six MK-82 500 pound general purpose bombs, two 370-gallon external tanks and a centerline external ECM pod. The mission profile shows a high altitude cruise to and from the target plus one hour loiter. A combat allowance for 5 minutes at Military power at sea level with the air-to-surface weapons is included. The mission radius is depicted with and without retaining the external tanks.

A strike interdiction mission in the F-16 would look like that depicted in Figure 12. In this case the aircraft is loaded with two AIM-9 missiles, two MK-84 2,000 pound general purpose bombs, two 370-gallon external fuel tanks and a centerline external ECM pod. Again the external fuel tanks are dropped when they are empty. This mission profile would call for a high, low, high ingress and egress to and from the target. A 100 Nautical Mile low level navigation at 550 knots is planned in and out of the target area. A 5 minute allowance at Military power and sea level is used for weapons delivery.

A typical low level all the way mission from the same locations is depicted in Figure 13. Again, the aircraft is loaded with 2 AIM-9 missiles, 6 MK-82 500 pound general purpose bombs, two 370-gallon external tanks, and a centerline external ECM pod. Low level cruise to and from the 100 Nautical Mile high threat penetration point is made at 400 knots. A one hundred Nautical Mile dash to and from the target is made at 550 knots. Again a 5 minute allowance at Military power and sea level is used to deliver the bombs. In this case, the external fuel tanks are retained on the return leg.

The F-16 has surprisingly good low level ride qualities for an aircraft with this wing loading. The relatively stiff fuselage structure, the variable camber of the leading edge flaps and the motion command flight control system all contribute to the smooth ride. My theory is that the fuselage lift and the wing wash out combine to actually down load the wing tip during high speed, low level cruise. This appears to decrease the effective wing area and produce ride qualities of a fighter with a much higher wing loading.

The last mission described for the F-16 is the sea surveillance or sea attack mission shown in Figure 14. Here the aircraft is configured with 2 AIM-9 missiles, 2 Harpoon anti-shipping missiles with electro-optical terminal guidance, two 370-gallon external fuel tanks and a centerline ECM pod. The external fuel tanks are dropped when empty. High altitude cruise to and from the target is used with a 50 Nautical Mile dash to and from the target at 550 knots and low altitude. Again 5 minutes at sea level and Military power is allowed for weapons delivery.

The results of a dedicated team effort of General Dynamics, Pratt & Whitney, Westinghouse, the U.S. Air Force, European participating governments of The Netherlands, Norway, Denmark and Belgium are shown in Figure 15. The performance requirements of the F-16 were met or exceeded. Testing is essentially complete. Manufacturing is on schedule with as of 15 October, 46 U.S. Air Force aircraft delivered; 17 aircraft have been delivered off the European production lines in Belgium and The Netherlands. The original cost objectives of the F-16 program are being met. The mission growth capability of the F-16 has been demonstrated.

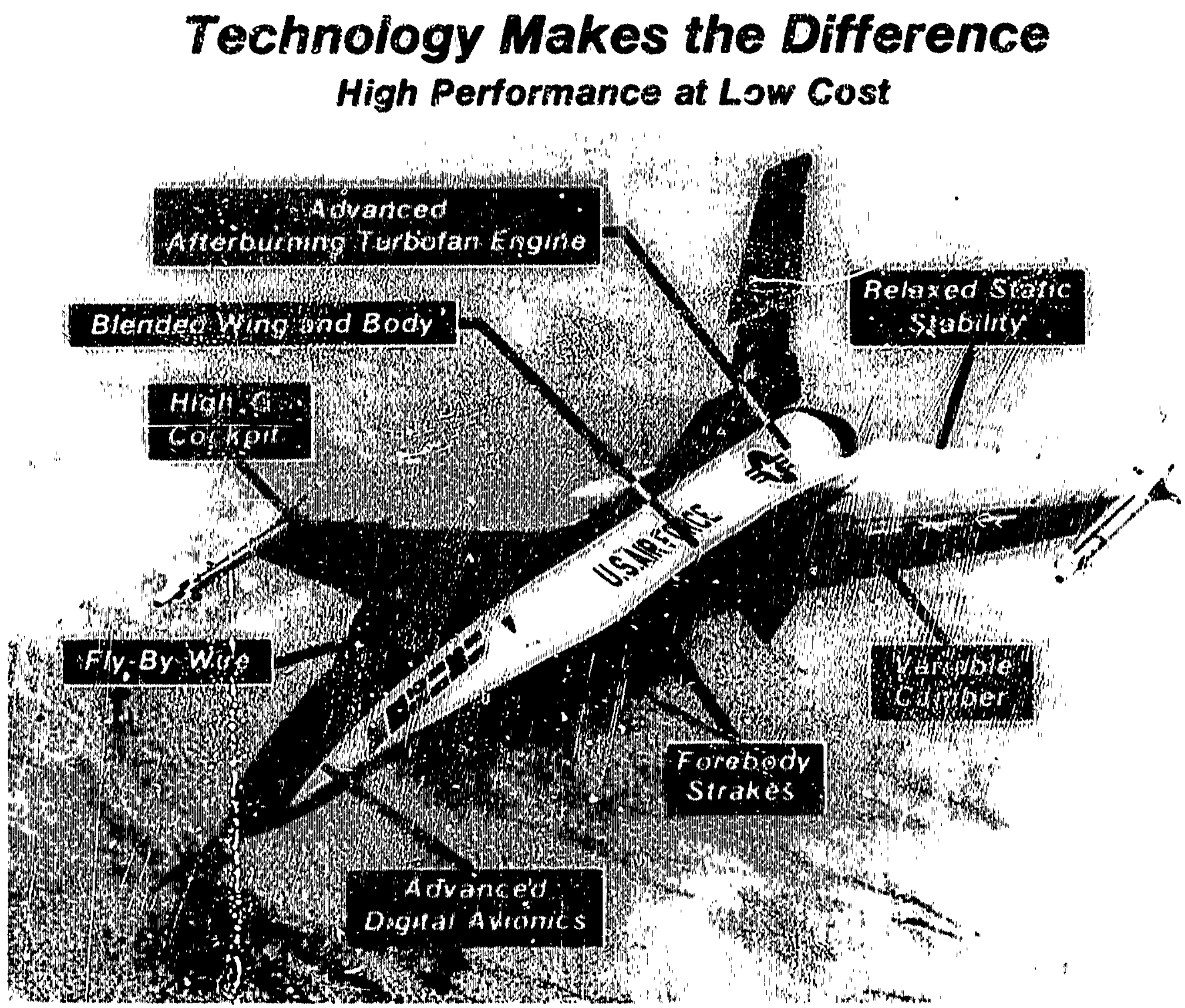


Fig.1 Advanced technologies

The F-16 Multirole Fighter

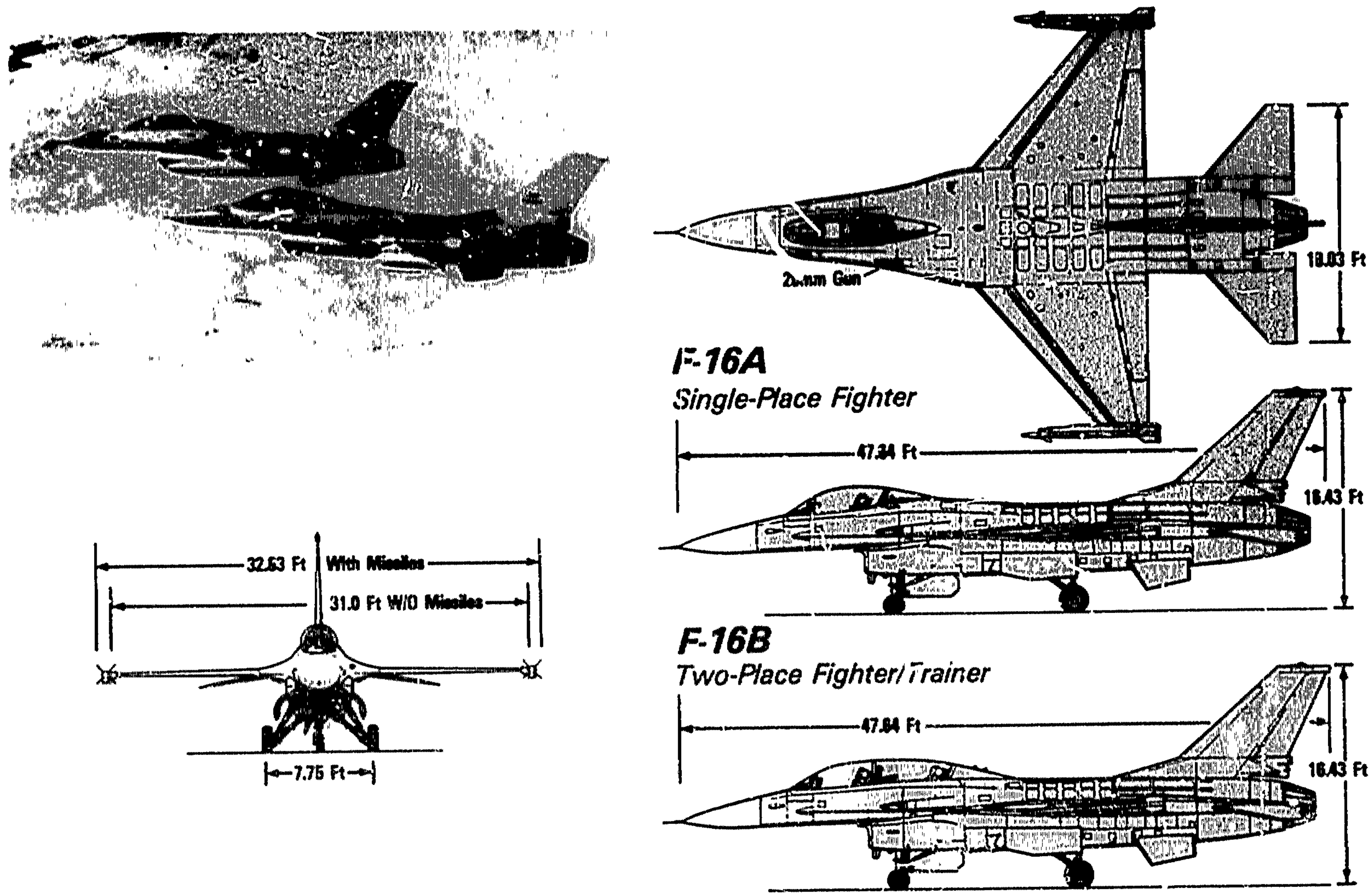


Fig.2 General arrangement

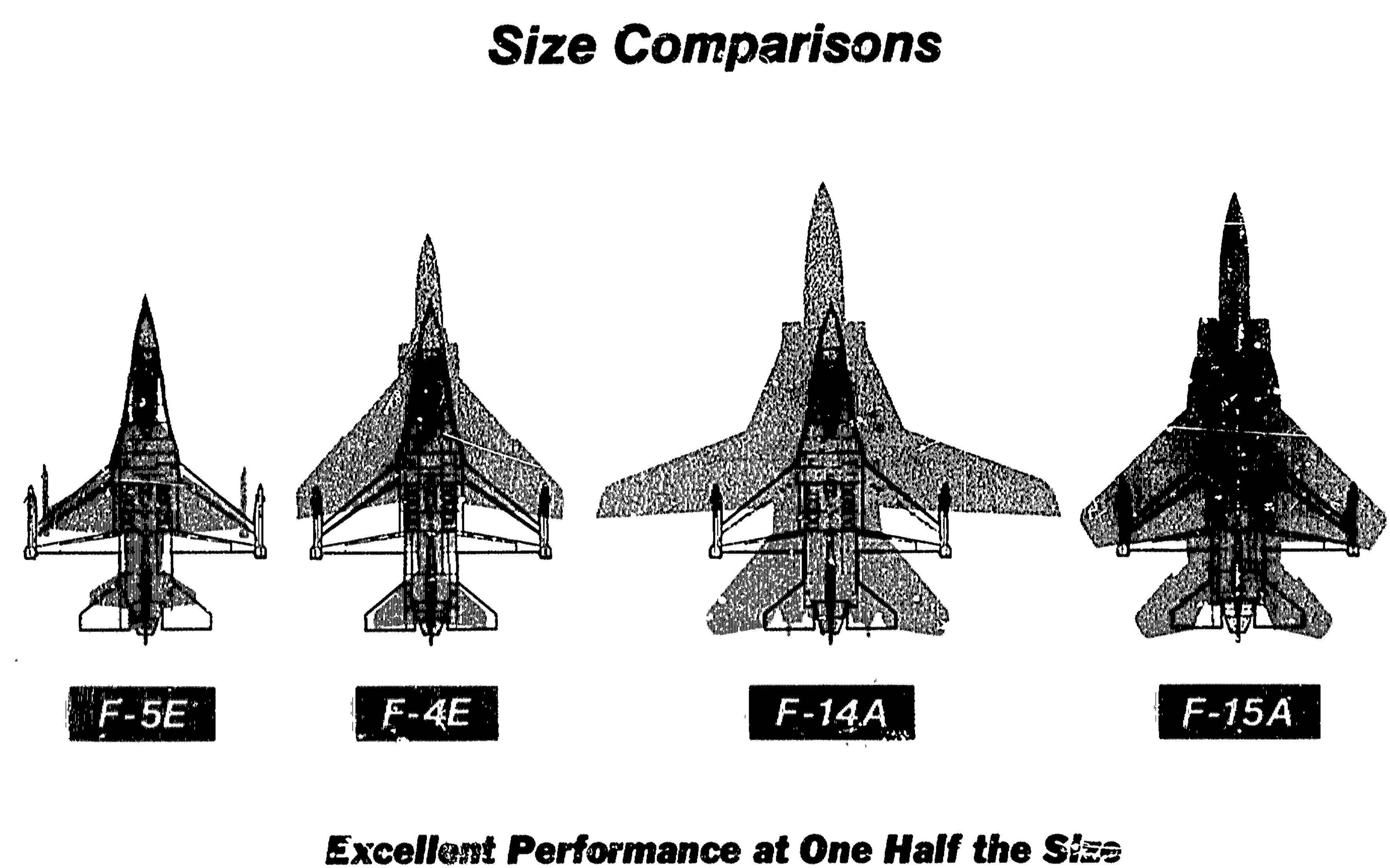


Fig.3 Size comparisons

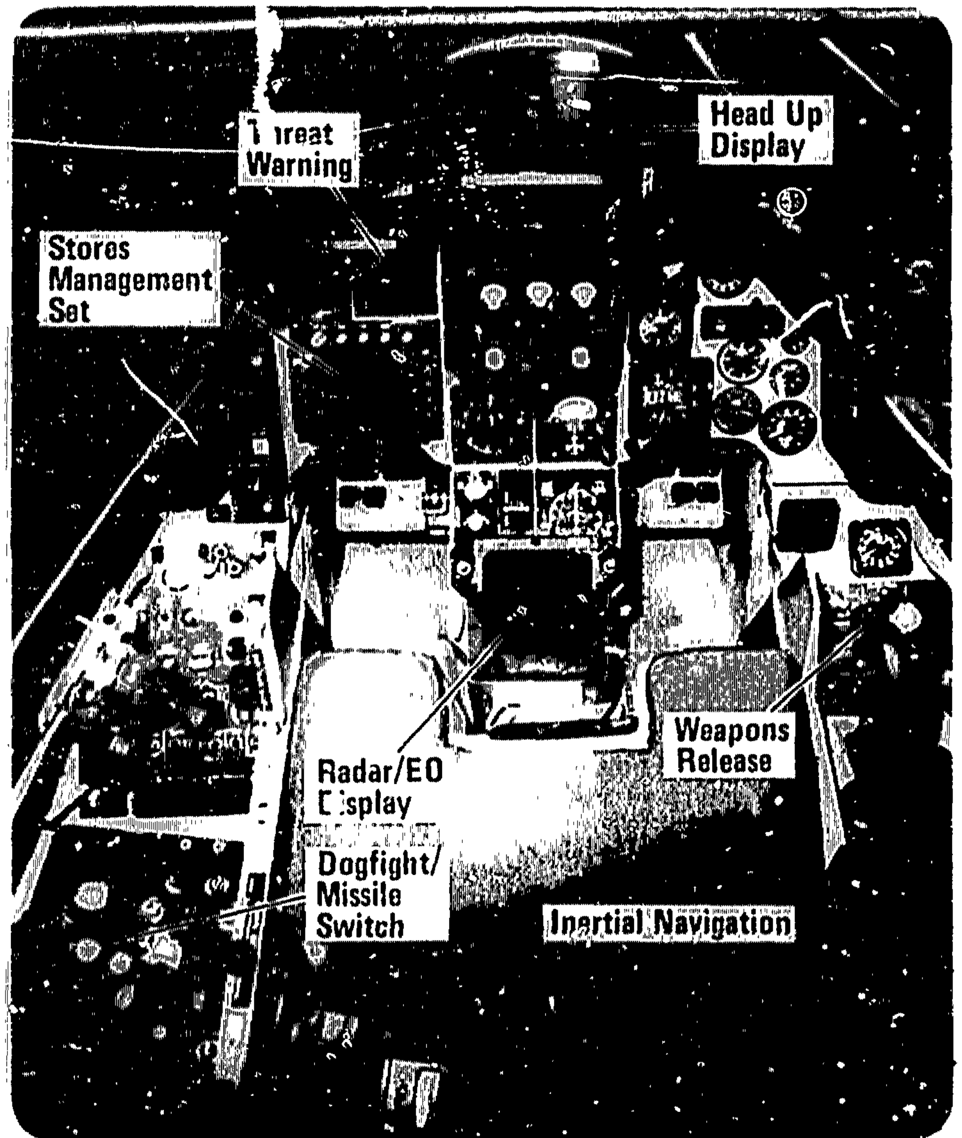


Fig [illegible] Cockpit displays and controls

F-16 Cockpit Displays/Controls

- Head-Up and Hands-On-Throttle-and-Stick Control of the Weapon System
- Up-Front Mission Mode Displays and Controls
- Computer Generated Flight and Weapon System Information.

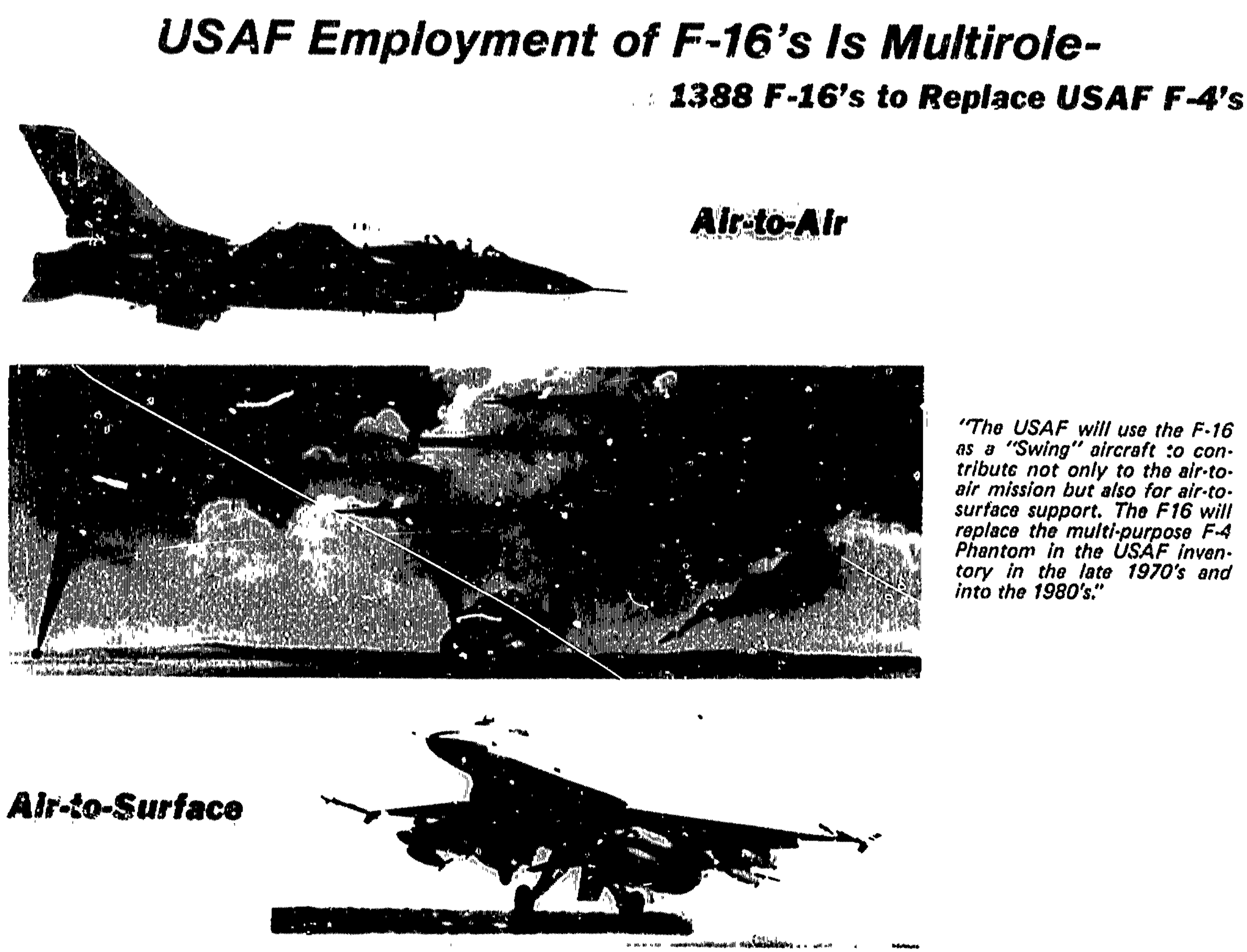


Fig.5 Employment concept

F-16 Multirole Weapons Delivery Capability

Air-To-Air

- Radar Search, Detection and Track (Lookup and Lookdown)
- Air Combat Auto Acquisition
- AIM-9 Missile Mode
- Lead Computing Optical Sight (LCOS) and Snapshoot Gun Mode
- Single Switch Transfer (Air-to-Surface to Dogfight/Missile)
- Energy Maneuverability

Air-To-Surface

- Visual Delivery Modes
  Continuously Computed Impact Point (CCIP)/Dive Toss/
  Depressed Reticle
- Doppler Beam Sharpened Ground Map
- Blind Delivery Mode
  Continuously Computed Release Point (CCRP)/Beacon/
  Low Altitude Drogue Delivery (LADD)
- Electro-optical Mode
- Laser Spot Tracker

Fig.6 Weapons delivery capability

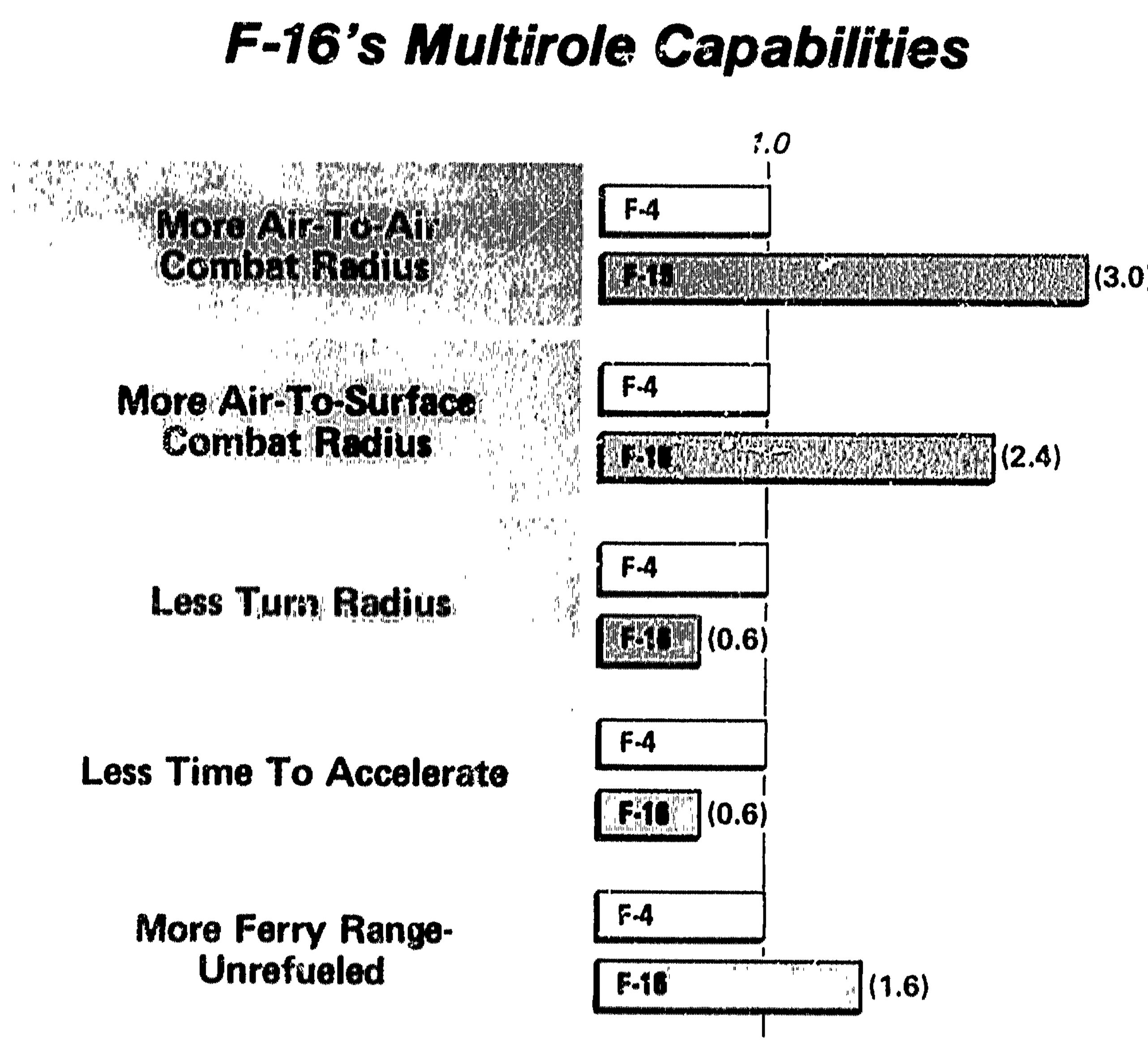


Fig.7 Performance capabilities

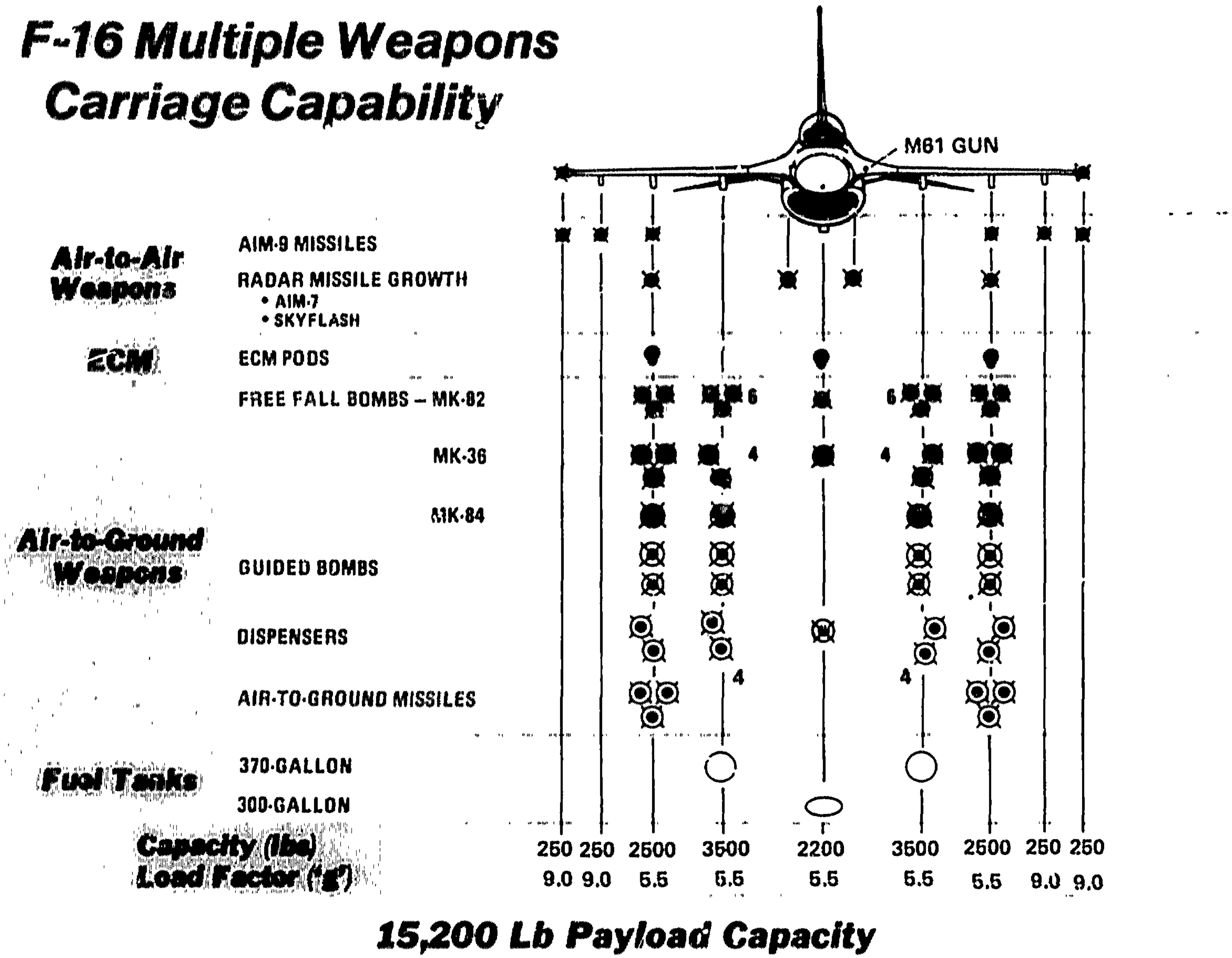
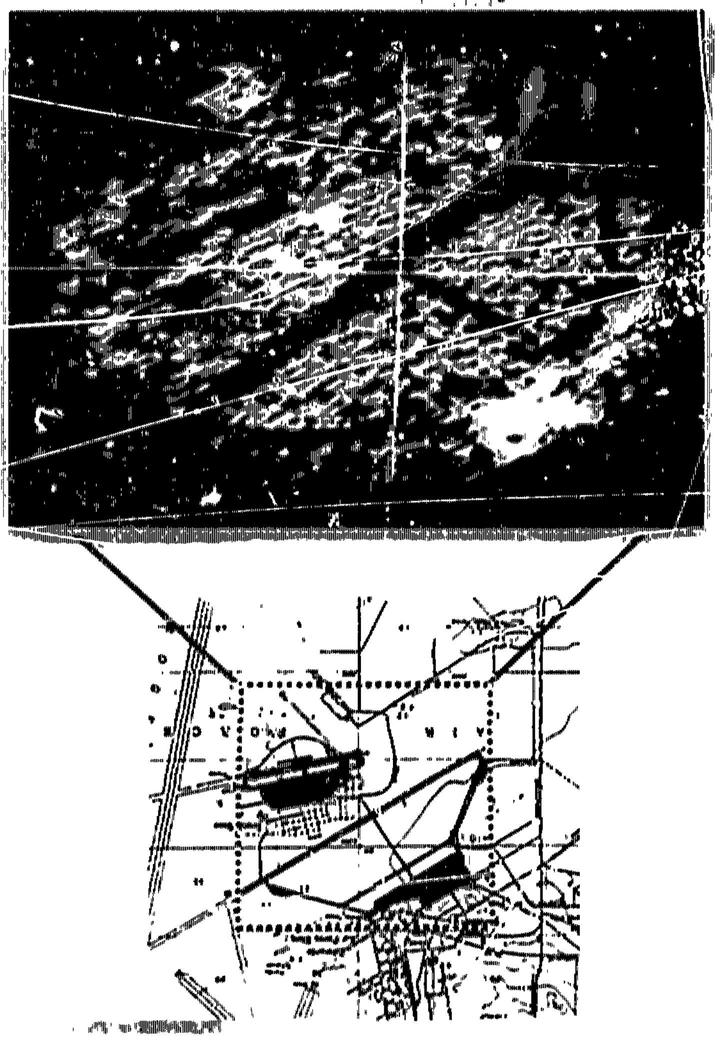


Fig.8 Weapons carriage capability

Demonstrated Air-to-Surface Radar Performance

Radar Ground Map

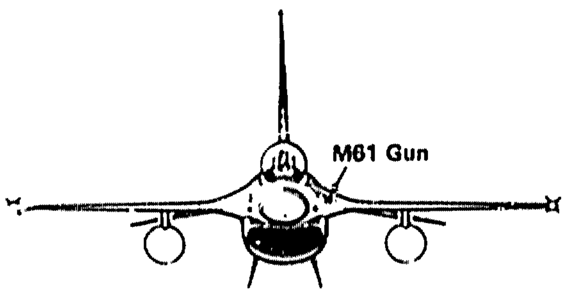


[illegible]	[illegible]
TARGET AZIMUTH RESOLUTION	20% BETTER THAN SPEC
TARGET RANGE RESOLUTION	MEETS NEW USAF SPEC
DOPPLER BEAM SHARPENING	20% BETTER THAN SPEC
BLIND BOMBING ACCURACY	WELL WITHIN SPEC
VISUAL BOMBING ACCURACY	WELL WITHIN SPEC
BEACON	250% BETTER THAN SPEC RANGE
SEA 1	10% BETTER THAN SPEC RANGE
SEA 2	10% BETTER THAN SPEC RANGE

Fig.9 Ground map radar performance

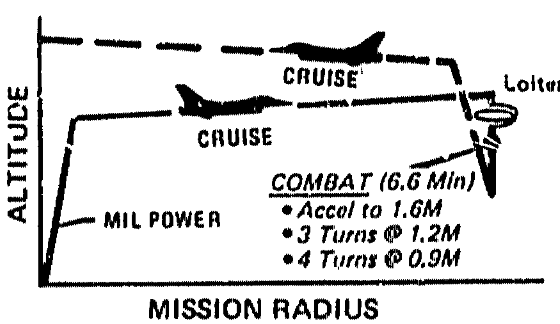
Air Superiority Mission
NATO Central & Northern Europe

Configuration



(2) AIM-9 Missiles
(2) 370-Gal Tanks-Dropped

Mission Profile



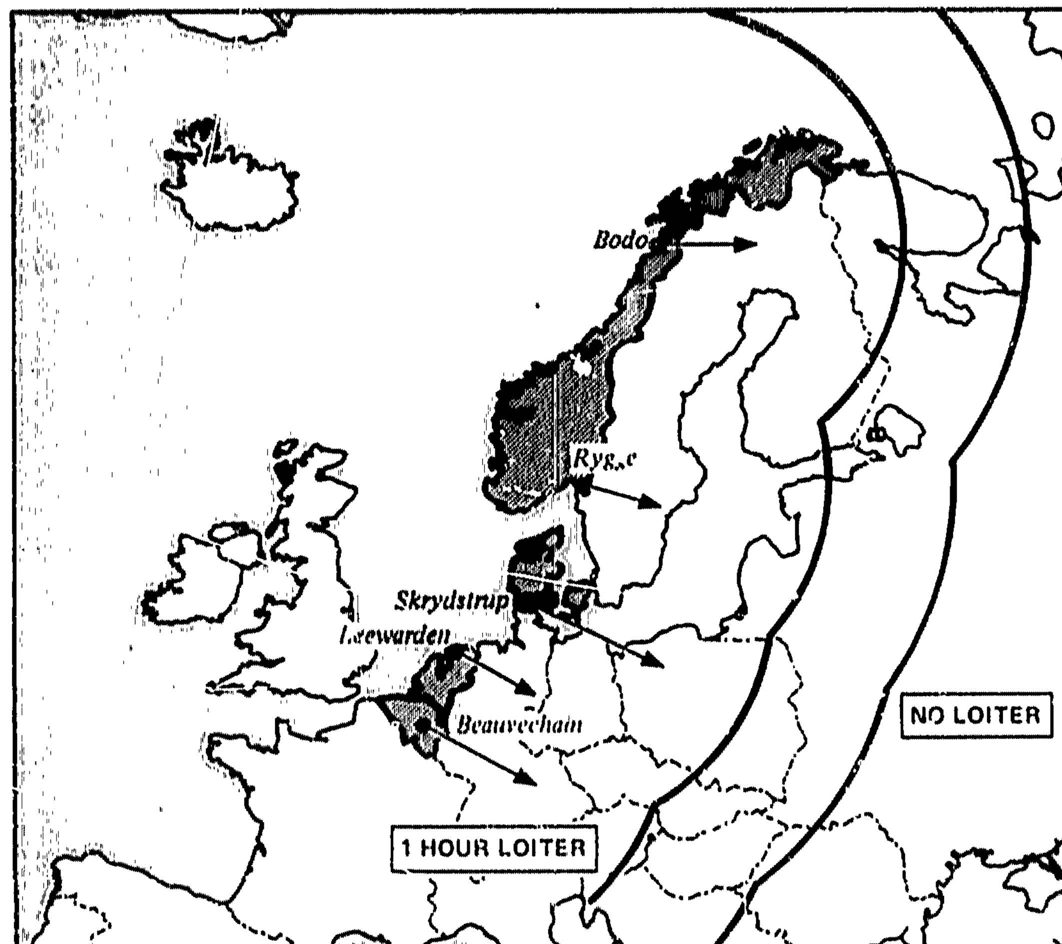
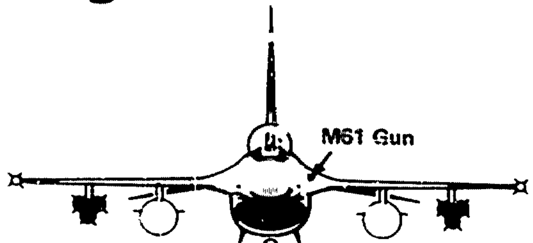


Fig.10 Air superiority mission

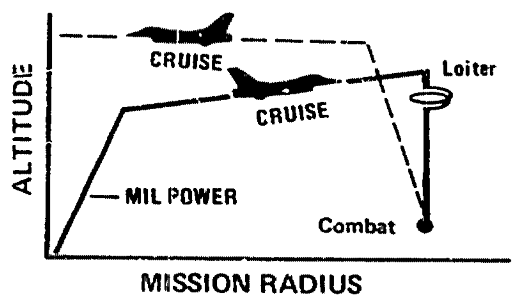
Close Air Support Mission
NATO Central & Northern Europe

Configuration



(2) AIM-9 Missiles
(6) MK-82 Bombs
(2) 370-Gal Tanks
(1) ECM Pad

Mission Profile



COMBAT

- *5 MIN IN MIL POWER AT SEA LEVEL AT M.9 WITH WEAPONS*

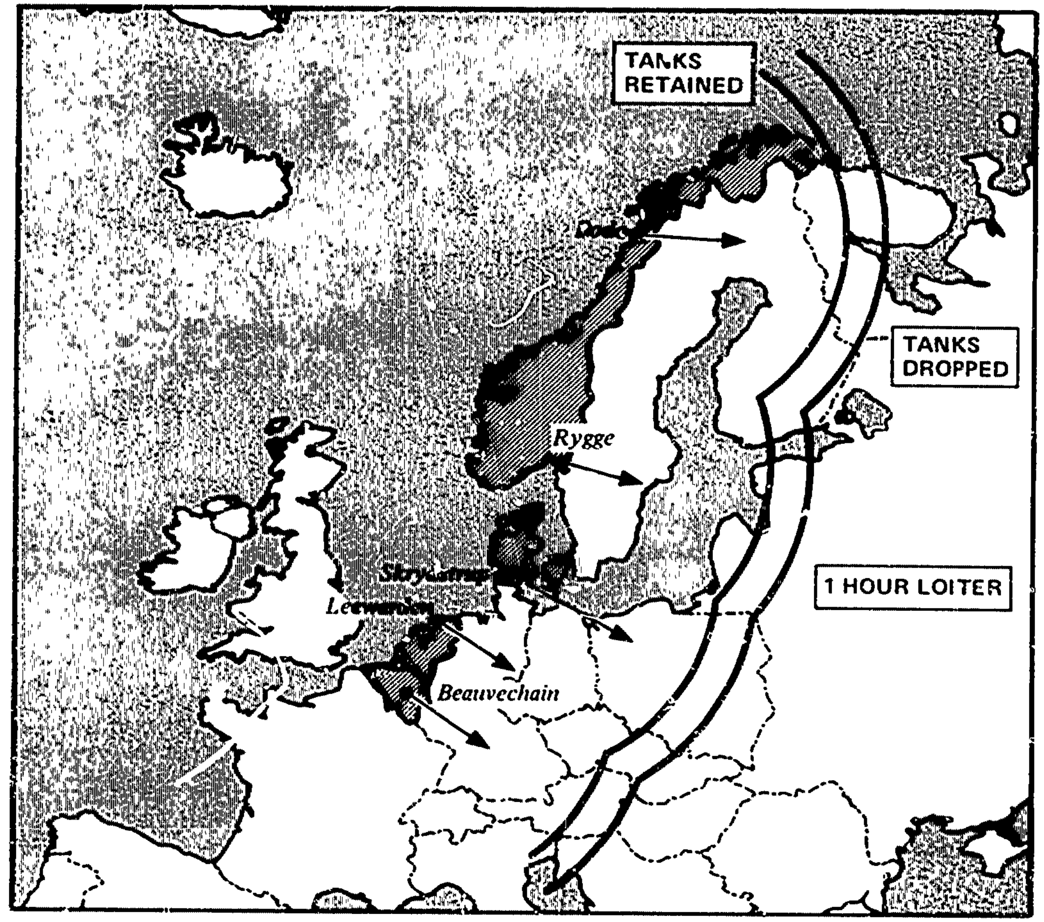


Fig.11 Close air support mission

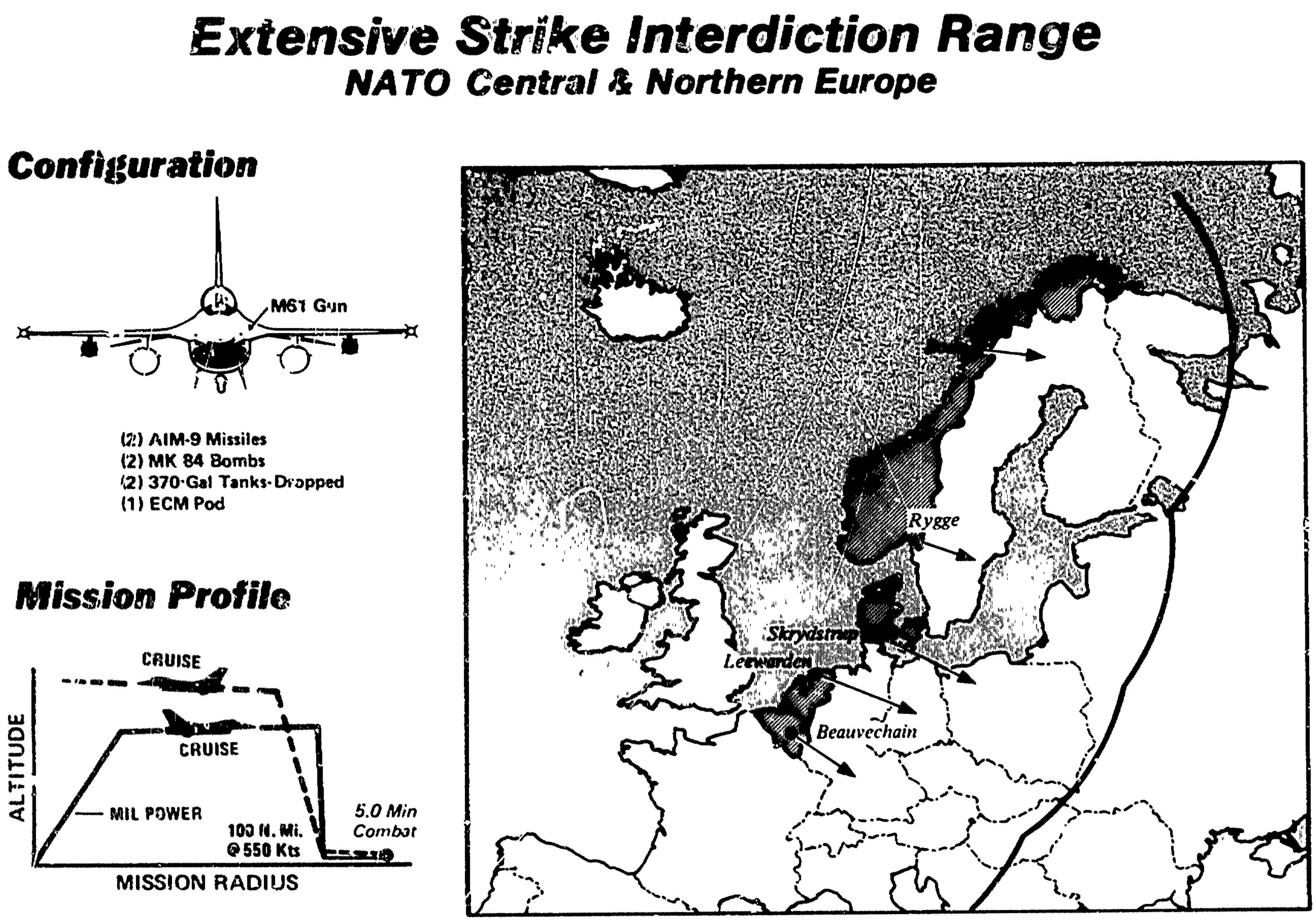


Fig.12 Strike interdiction mission

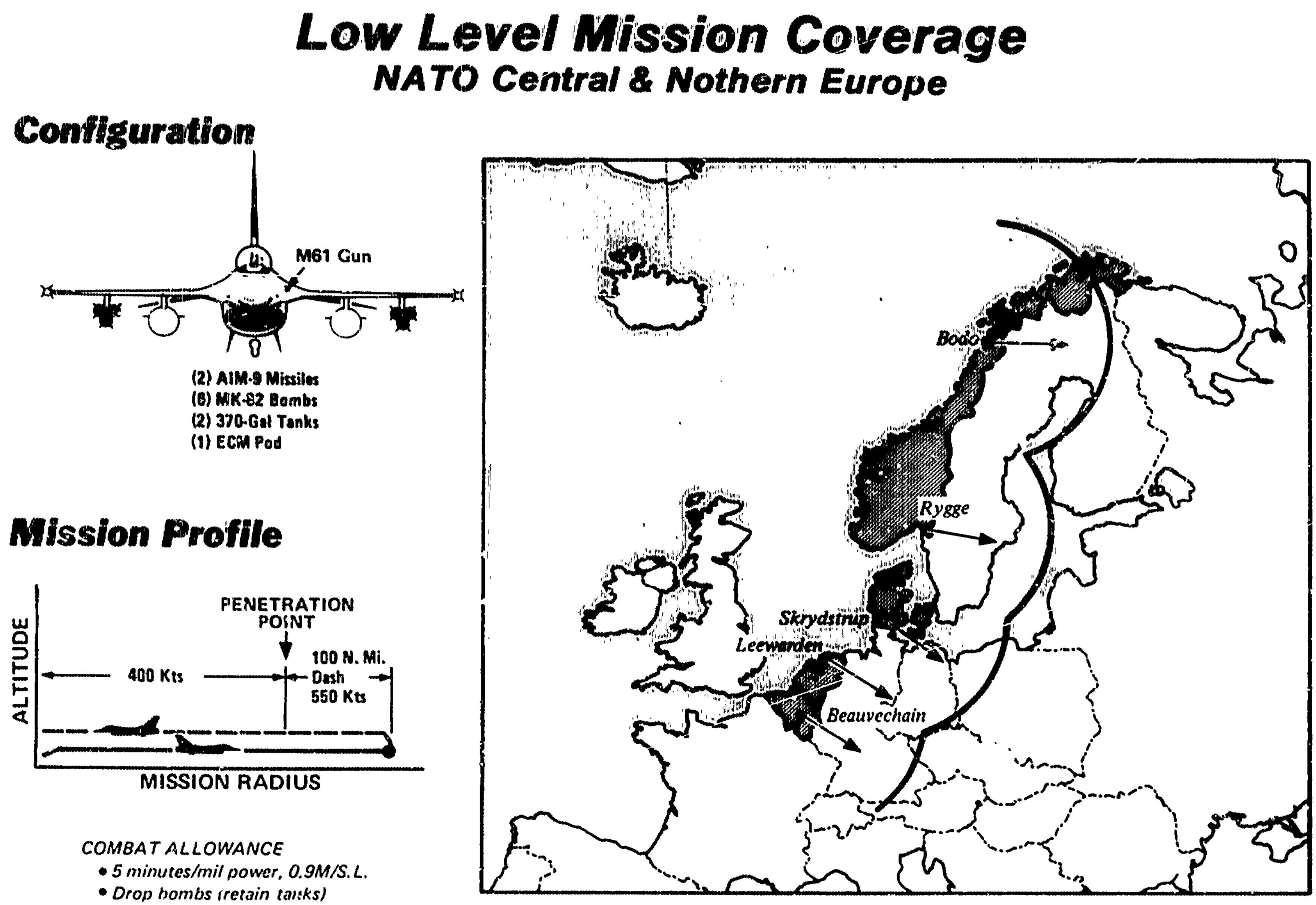
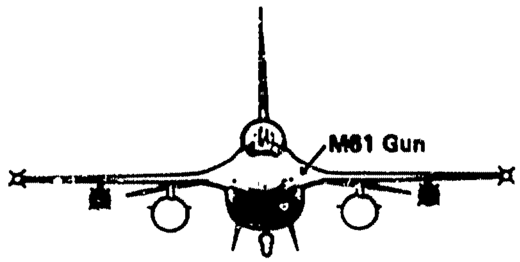


Fig.13 Low level mission

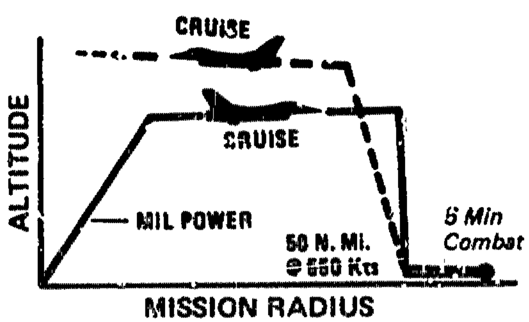
Protecting the Sea Lanes
NATO Central & Northern Europe

Configuration



(2) AIM-9 Missiles
(2) Harpoons (AGM-84's)
(2) 370-Gal Tanks-Dropped
(1) ECM Pod

Mission Profile



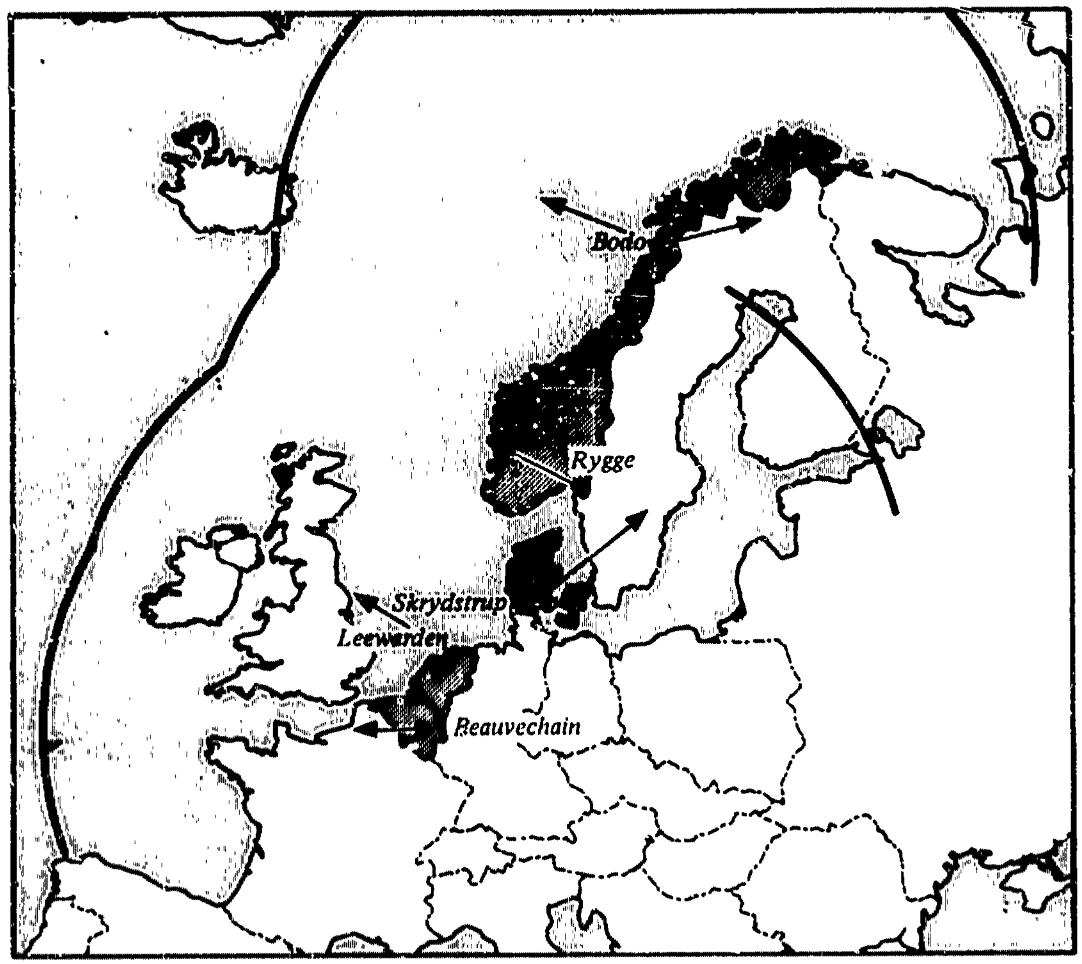


Fig.14 Sea surveillance and anti-shipping mission

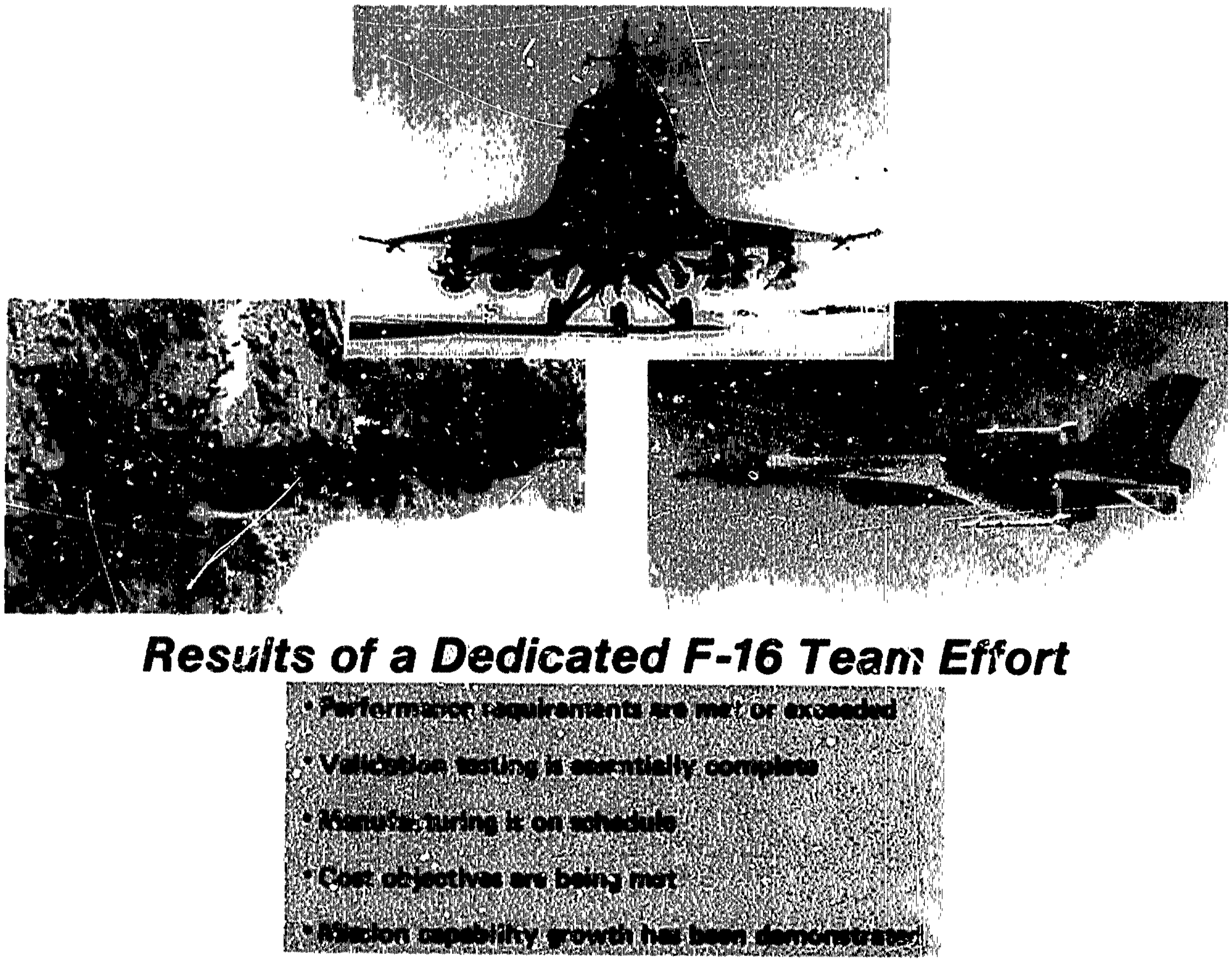


Fig.15 Summary

MISSIONS OPERATIONNELLES ET CONCEPTION DU MIRAGE 2000

Colonel JACQUES GUILLOU
Etat-Major de l'Armée de l'Air/
Bureau des Programmes de Matériel
24 Boulevard Victor 75015 PARIS

SOMMAIRE

Le programme MIRAGE 2000 décidé en décembre 1975 vise à assurer le remplacement du MIRAGE III dans toutes ses versions.

La première version du MIRAGE 2000 a une vocation privilégiée de défense et de supériorité aérienne et doit être capable de l'interception d'hostiles à très haute altitude, de la destruction des hostiles pénétrant à basse altitude, et d'engager le combat aérien rapproché à armes égales avec les meilleurs chasseurs de sa génération.

Le MIRAGE 2000 avion de combat monoplace mono-réacteur SNECMA M 53 conçu pour satisfaire ces exigences se caractérise par le retour à une formule d'aile delta, améliorée par l'utilisation de commandes de vols électriques.

Les capacités de manoeuvrabilité du MIRAGE 2000 marquent un progrès fondamental par rapport aux avions précédents et conduiront à de nouvelles tactiques de combat.

1. - GENERALITES.

Dans l'ensemble des forces aériennes, l'aviation de chasse est constituée d'unités qui par les caractéristiques propres de leur matériel et les qualités de leur personnel, peuvent être engagées aussi bien contre les objectifs de surface que contre les objectifs en vol.

Par l'étendue de son rôle et de ses missions, par la diversité de ses modes d'actions, elle met aussi pleinement à profit la souplesse d'emploi, qualité fondamentale de l'arme aérienne, dans une appropriation constante du moyen aérien au but recherché.

Jusqu'à un passé récent, pour conserver cette souplesse d'emploi, l'Armée de l'Air a cherché à faire exécuter par les mêmes pilotes et les mêmes avions d'une unité aussi bien les missions d'attaque au sol que les missions de défense aérienne.

Mais devant l'extension des opérations au domaine tout temps de jour et de nuit, le développement des capacités nucléaires des chasseurs bombardiers, l'extension [illegible] du contrôle des opérations défensives et offensives, le développement des engins air-air, air-sol et sol-air avec ses conséquences sur les missions tactiques et le développement des moyens de guerre électronique, la spécialisation des équipages est devenue indispensable afin d'assurer l'utilisation efficace des systèmes de navigation et d'attaque.

Ces critères ont conduit aussi à spécialiser les systèmes d'armes ce qui fût le cas pour les programmes JAGUAR et MIRAGE F1, et les pilotes sont devenus rapidement opérationnels dans leur mission principale avec ces types d'appareils.

La conception des avions de la nouvelle génération doit tenir compte des expériences des conflits précédents.

Il est apparu en particulier que les avions d'attaque au sol les plus efficaces étaient ceux qui avaient une bonne manoeuvrabilité car ils étaient plus aptes à engager un combat ou à l'éviter quand il leur était imposé.

Ce n'est pas seulement le rayon d'action le plus grand qui fait le meilleur avion de pénétration. Un chasseur de grande manoeuvrabilité peut être alourdi par des réservoirs supplémentaires et l'armement nécessaire pour l'attaque, et redevenir rapidement un combattant aérien de grande classe après l'avoir largué.

De plus le développement d'un moteur militaire de grande classe demande une dizaine d'années et représente un investissement financier important ; il faut donc définir un moteur réalisant un bon compromis entre les performances demandées aussi bien en supersonique à haute altitude qu'à basse altitude pour les missions d'attaque au sol.

Aussi l'Armée de l'Air a la conviction qu'il faut partir de la notion d'un avion polyvalent au stade industriel seulement, c'est à dire un avion ayant le même moteur, le même fuselage (à quelques variantes près), la même voilure, et donnant naissance à plusieurs versions suivant les systèmes d'arme dont on l'équipera.

Ces versions seront destinées à l'interception et au combat d'un côté, à la pénétration et à la reconnaissance de l'autre.

Les spécifications opérationnelles du MIRAGE 2000 ont été rédigées avec cet objectif.

2. - SPECIFICATIONS OPERATIONNELLES DU MIRAGE 2000.

Le programme MIRAGE 2000 décidé en décembre 1975 vise à assurer le remplacement à partir de 1982 des MIRAGE III dont la mise en service remonte à 1960.

L'avion monoréacteur de combat MIRAGE 2000 est essentiellement défini pour satisfaire au maximum les exigences opérationnelles de défense et de supériorité aérienne.

On devra cependant pouvoir en dériver des versions adaptées à l'exécution des missions d'attaque au sol et de reconnaissance à partir de la même cellule, mais pourvues d'équipements spécifiques de leur mission ainsi qu'une version biplace d'entraînement équipée de système d'arme.

2.1. - Généralités.

L'avion doit être capable d'effectuer toutes les missions de défense et supériorité aérienne :

- interception des avions ennemis volant à grand mach et à haute altitude,
- détection et destruction en vol des avions pénétrant à basse altitude,
- engageant des chasseurs ennemis en combat aérien.

L'exécution de ces missions exige :

- des performances élevées en accélération supersonique et en plafond stabilisé ainsi que des qualités de manoeuvrabilité et de maniabilité nécessaires aux évolutions de combat,

- une capacité importante de détection autonome des raids en particulier dans le domaine de la basse altitude,

- un armement adapté.

En mission secondaire cet avion devra pouvoir être capable d'effectuer des missions d'attaque au sol avec des armements classiques.

L'emploi de cet avion doit satisfaire aux exigences d'une bonne mobilité tactique, grâce en particulier, à des moyens de mise en oeuvre réduits.

2.2. - Caractéristiques générales.

2.2.1. - Performances

Les principales performances demandées peuvent être résumées comme suit :

- vitesse d'approche dans la gamme 140 à 150 kts (suivant la configuration),

- utilisation de piste de 1200 mètres à la masse maximale,

- vitesse maximum :

  à haute altitude : mach 2,2
  à basse altitude : 800 kts

- plafond pratique avec deux missiles de longue portée supérieur à 55 000 pieds,

- destruction de l'hostile à 75 000 pieds M 2,5 moins de 5 mn après le décollage,

- excellente manoeuvrabilité au combat tant en supersonique qu'en subsonique, le but étant de pouvoir utiliser l'avion avec le minimum de contraintes dans tout le domaine de vol et dans toutes les configurations.

En particulier on cherche à obtenir pour le combat aérien :

- des changements de trajectoires rapides ce qui implique :

  . une maniabilité excellente (mouvement autour du centre de gravité très rapide)
  . la trajectoire la plus serrée possible (marges et limites de manoeuvre)

- une bonne pilotabilité dans les grandes incidences,

- une réponse avion très rapide et très précise en passe de tir,

- un pilotage aisé de l'avion au delà des limites du domaine de la stabilité naturelle.

2.2.2. - Propulseur

L'avion est équipé du moteur SNECMA M 53-5, mais devra être capable de recevoir une version améliorée de ce moteur moyennant des modifications mineures.

Le comportement du moteur aux grandes incidences doit faire l'objet d'un soin particulier.

2.2.3. - Système d'armes

L'architecture du système d'armes doit posséder une grande capacité d'évolution et d'adaptation des différents composants.

Le radar constitue l'élément essentiel du système d'armes et doit avoir une portée importante afin d'intercepter les avions à hautes performances et de disposer d'une capacité de détection autonome suffisante en particulier dans le domaine de la basse altitude.

Il doit être conçu pour pouvoir utiliser les missiles MATRA SUPER 530 à longue portée ; il peut également être utilisé au profit des missiles de combat MATRA 550 MAGIC, et de la conduite de tir canons.

L'avion doit conserver le maximum de ses capacités offensives en "ambiance électronique hostile".

En plus des possibilités de résistance au brouillage offertes par le radar, l'avion doit posséder :

- un système de détection goniométrique des radars des conduites de tir adverses,
- un ensemble détecteur brouilleur.

2.2.4. - Organisation du poste pilote

Afin de réduire la charge de travail du pilote la représentation des informations strictement nécessaires pour chaque phase de la mission sera réalisée sur des visualisations à tube cathodique ; en particulier toutes les informations nécessaires à l'exécution de la phase finale de l'attaque et celles concernant sa sûreté devront bénéficier d'une présentation privilégiée et les commandes correspondantes être d'un accès rapide et aisé.

3. - LES ORIENTATIONS TECHNIQUES

Pour donner au MIRAGE 2000 les caractéristiques et performances ci-dessus, les solutions techniques adoptées peuvent être classées en trois catégories :

- conception de la formule et du système de pilotage,
- solutions structurales,
- conception du système de navigation, de conduite de tir et d'attaque.

3.1. - Formule retenue et système de pilotage

L'aptitude au combat et la capacité d'accélération supersonique à haute altitude sont les objectifs primordiaux ; ceci suppose pour une motorisation donnée (moteur M 53-5 ou dérivés directs), la recherche simultanée d'un rapport "poussée/poids" aussi élevé que possible et d'une charge alaire aussi faible que possible cette dernière caractéristique étant également déterminante pour des vitesses de décollage et d'approche.

Ceci doit être néanmoins obtenu sans pénalité excessive sur la traînée puisque la capacité d'accélération ou de vitesse ascensionnelle, à un poids donné, est proportionnelle à l'excédent de poussée (différence poussée moins traînée).

En manoeuvre serrée sous forte incidence il est en outre indispensable de minimiser les traînées supplémentaires correspondantes (traînée induite et traînée d'équilibrage majorées sans facteur de charge).

La société AMD-BA après étude de différentes formules aérodynamiques, a proposé le meilleur compromis entre poids et performances avec une solution d'aile delta en forte flèche, en retenant les options principales suivantes :

- optimisation du squelette et des profils de voilure, avec adjonction d'un bord d'attaque mobile, de manière à réaliser le compromis suivant :

  . faible traînée de forme dans tous les cas de vol à faible incidence (phase d'accélération supersonique, croisières rapides à basse ou moyenne altitude),
  . amélioration de la finesse à forte incidence (marge de manoeuvre en combat phases de vol à basse vitesse),
  . réduction de la traînée d'équilibrage en palier et report des "accidents de stabilité longitudinale à incidence élevée (limites de manoeuvre)".

- choix d'une charge alaire faible de 215 kg/M2 en combat.

- épaississement modéré des emplantures de voilure, combinant une meilleure interaction voilure-fuselage, une réduction de poids dans la partie structurale la plus chargée et une logeabilité plus grande,

- adoption d'une dérive à grand allongement permettant de conserver une bonne stabilité de route à grande incidence.

- amélioration du fonctionnement en incidence des entrées d'air par des dispositifs spéciaux,

- optimisation des commandes de vols électriques avec adoption de chaînes multiples "bouclées" entre la "demande pilote" et la réponse avion.

Cette ensemble permet de tirer le meilleur parti possible des gouvernes (quatre élevons, un gouvernail) tant au point de vue des performances qu'à celui des qualités de vol ; les commandes de vol électriques apportent bien entendu le maximum d'avantages dans tous les cas de fonctionnement associés à des marges de stabilité nulles ou négatives.

- visibilité importante du poste de pilotage par l'adoption d'un pare-brise panoramique monopièce.

3.2. - Solutions structurales

Le recherche d'un rapport "poussée/poids" élevé supérieur à 1 en combat, implique une construction légère obtenue essentiellement par

- le choix d'une formule delta sans empennage horizontal. L'aile basse conduit à un poids total plus faible en évitant le logement du train d'atterrissage dans le fuselage,

- l'adoption d'une structure intégrale pour la coque de fuselage et la voilure,

- l'épanouissement des formes de fuselage aux emplantures d'ailes pour réduire le poids des attaches,

- l'utilisation des matériaux composites,

- atterrisseur principal simplifié,

- adoption de freins au carbone dimensionnés pour éviter l'emport d'un parachute-frein et compenser l'alourdissement dû à la crosse d'arrêt.

3.3. - Le moteur M 53

Le réacteur SNECMA M 53 a été conçu pour équiper les avions de combat à hautes performances. Il allie simplicité et robustesse.

C'est un réacteur monocorps double flux à faible taux de dilution (0,4) et à taux de compression moyen (8,5).

Bien qu'adapté aux grandes vitesses à haute altitude avec post-combustion, sa consommation spécifique en réacteur sec est honorable, ce qui permet de l'utiliser de manière polyvalente à haute et basse altitude.

La poussée actuelle du moteur M 53 est de 9 T mais des améliorations notamment dans le domaine des matériaux et des températures devant turbine vont permettre d'obtenir prochainement 10 T sur une version améliorée.

4. - NOUVEAUX DOMAINES OFFERTS PAR LE MIRAGE 2000.

Le MIRAGE 2000 apporte un gain substantiel de performances en missions d'interception ou de combat par rapport aux avions MIRAGE III et MIRAGE F1.

EN mission d'interception les temps de montée supersonique ont été diminués de moitié et c'est ainsi que le MIRAGE 2000 est capable de détruire un hostile à 75.000 pieds mach 2,5 cinq minutes après le lâcher des freins.

Les plafonds en vol stabilité ont été augmentés de 20 %.

En ce qui concerne la manoeuvrabilité, le gain obtenu en facteur de charge maximum instantané est de 80 %, mais il est évident qu'on ne peut profiter pleinement de ces possibilités nouvelles dans tout le domaine de vol à cause des limites de résistance de la cellule et du pilote.

Les facteurs de charge soutenus se sont améliorés dans des proportions considérables allant de 55 % en subsonique jusqu'à 130 % à mach 2.

Il faut noter que dans le même temps les basses vitesses ont été très diminuées,et offrent des possibilités de combat au dessous de 100 kt à 25° d'incidence tout en conservant une maîtrise totale de l'avion par l'absence de buffeting, les grandes capacités d'évolution à ces vitesses faibles et un contrôle parfait des trajectoires pilotées.

Les qualités de maniabilité se caractérisent par des taux de rotation instantanés en tangage et en roulis extrêmement rapides et inconnus jusqu'alors.

Ces nouveaux domaines d'altitude, de facteurs de charges soutenus, de maniabilité permettant des changements de trajectoire extrêmement rapides, ont été pris en compte au niveau de la conception de l'appareil, dans le but d'améliorer le confort de pilotage et la résistance physique du pilote.

Les améliorations concernent d'une part la recherche d'une bonne position du pilote dans la cabine pour qu'il puisse profiter pleinement des possibilités de son système d'armes, résister aux accélérations importantes permises par l'appareil, avoir la meilleure visibilité possible tous secteurs, et d'autre part assurer sa survie en cas de décompression à très haute altitude.

Le premier problème à régler était celui du positionnement du siège éjectable. Sur les avions MIRAGE précédents les sièges étaient déjà inclinés à 25° ; sur MIRAGE 2000 le siège a une inclinaison de 27°, et les jambes du pilote sont dans une position plus relevée. On est très rapidement limité au-delà de ces inclinaisons, d'une part pour des problèmes de trajectoire d'éjection, d'autre part par le positionnement du tableau de bord et surtout du viseur tête haute qui avec la visualisation cathodique des différentes symbologies est devenu l'instrument principal de pilotage, dont il faut pouvoir acquérir les informations rapidement ; ce dernier point fixe d'ailleurs une position d'oeil théorique, et c'est autour de lui qu'il faut régler le siège en hauteur. A partir de cette position il faut ensuite pouvoir profiter pleinement de la visibilité tous secteurs.

Le pare-brise panoramique et la verrière surélevée améliorent grandement la visibilité.

Pour améliorer le confort du pilote sous facteur de charge, l'habillage du baquet et du dossier du siège a été dessiné pour épouser au maximum la forme du corps. Les pilotes se sentent ainsi très bien callés, mais il demeure le problème de la torsion du cou sous forte accélération pour voir l'ennemi dans le secteur arrière.

En ce qui concerne la survie du pilote au dessus de 50.000 pieds en cas de décompression explosive, l'Armée de l'Air fait développer un vêtement simplifié qui protégera le pilote le temps de redescendre à 30.000 pieds. La durée d'habillage prend moins d'une minute et le casque pressurisé offre autant de visibilité qu'un casque classique. Les possibilités de combat avec cet équipement seront donc conservées.

5. - PROBLEMES PHYSIOLOGIQUES NOUVEAUX.

Malgré le bon compromis qui semble avoir été acquis pour positionner au mieux le pilote afin qu'il supporte les facteurs de charge élevés et puisse lire les informations nécessaires sur la planche de bord et les différentes visualisations cathodiques, les problèmes de résistance physiologiques en combat ne sont pas éliminés pour autant.

En effet le MIRAGE 2000 se caractérise par la possibilité extrêmement brutale de changer de trajectoire, et aussi par la capacité de maintenir longtemps des facteurs de charge élevés.

Les changements brutaux de trajectoire peuvent se faire sans précaution particulière, le système de commandes de vol électriques arrêtant la montée en incidence ou en facteur de charge à des valeurs fixées après essais en vol pour que l'appareil résiste structuralement et reste sain aérodynamiquement.

En ce qui concerne les taux d'accélération, les facteurs de charge maximum de 8g n'étaient obtenus sur les avions précédents qu'à basse altitude et ne pouvaient être maintenus que peu de temps la vitesse s'écroulant rapidement.

Il était par contre possible d'engager un combat tournoyant à 6g à 30.000 pieds et de maintenir ce facteur de charge de manière continue en perdant rapidement de l'altitude.

Sur MIRAGE 2000 pour certaines vitesses appropriées il est possible de maintenir 6 à 7g continus non pas en descendant mais en montant à plus de 20° de pente. De plus la zone où l'avion peut évoluer à 8g continus s'est agrandie non seulement dans le domaine des vitesses mais dans une grande gamme d'altitude.

Comme les avions de combat de la nouvelle génération, fortement motorisés, sont capables de ces facteurs de charge soutenus et ce d'autant plus que leur charge alaire est faible, il ne semble plus qu'il faille rechercher seulement la supériorité en combat dans des manoeuvres à "G" élevés continus, car les pilotes ne pourront pas suivre physiologiquement les capacités de leur machine ; les changements brutaux et rapides de trajectoire semblent préférables :

- ils permettent de prendre instantanément un avantage tactique, puis en relâchant la pression au manche d'analyser la situation, et de repartir pour une nouvelle manoeuvre brutale et instantanée, le but étant de se placer en position de tir soit avec missiles de combat rapproché soit aux canons.

Ces manoeuvres impliquent pour être supportées par le pilote que les équipements anti-G aient des temps de réponse homogènes avec les variations rapides de facteur de charge.

Enfin une source d'inquiétude provient de la tenue mécanique musculaire et nerveuse de la partie cervicale de la tête du pilote, mise à rude épreuve sous "g" soutenus ou hachés, et qui doit continuer à être mobile sur les trois axes pendant ces phases de combat, l'oeil et le cerveau humain restant le meilleur capteur et le meilleur analyseur de situation.

CONCLUSION

La dernière génération des avions de combat du type MIRAGE 2000 fait découvrir une dimension nouvelle en matière de capacités manoeuvrières. Mais elles a aussi sa rançon. Il devient en effet indispensable de développer plus que jamais les simulateurs représentatifs et des avions biplace d'entraînement destinés à démontrer les possibilités de la machine et les tactiques de combat, mais aussi peut être à vérifier l'aptitude physiologique des équipages à évoluer dans ces nouveaux domaines.

Mais peut être aussi, faudra-t-il encore plus qu'aujourd'hui, entretenir physiquement les équipages et vérifier que leur organisme supporte normalement les agressions subies.

THE CAPABILITIES AND OPERATIONAL ROLES OF ROYAL AIR FORCE TORNADOS

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SUMMARY

The concept of producing a multi-role aircraft designed to meet the complexities of a number of roles was reached only after extensive computer analysis had shown the way ahead. For the RAF, the air-to-ground task and the air-to-air task calls for differing operating capabilities, but Tornado can meet these requirements. In its IDS version, the aircraft will be able effectively to carry out the roles of counter-air, interdiction, close air support, maritime attack, and reconnaissance. Moreover, it will be able to do so at very high speed and very low altitude, regardless of weather. The ADV, on the other hand, will use its powerful long range multi-target radar, advanced avionics with computerised mission planning, and automatic attack features, together with its missile armament, to make it the most effective interceptor available for the air defence of the UK's large strategic area. Backing this very wide range of capabilities, will be a comprehensive maintenance system of support, designed from the outset to optimise fault diagnosis, and keep the aircraft ready to fly with the minimum delay. The RAF has had many distinguished aircraft in its service throughout the years, but the introduction of Tornado into front-line service will make a significant increase in the RAF's fighting capability for both defensive and offensive operations.

HISTORICAL BACKGROUND

1. The demise of the TSR2 in the 1960s led to a fundamental reappraisal, by the RAF, of the roles of tactical strike and reconnaissance. As a result, some twelve years ago, operational research work was started to investigate the feasibility of counter-air and interdiction operations in the 1980s. A comprehensive computer simulation was constructed to represent a series of realistic attacks against airfields and interdiction targets. In order to programme the computer, factors such as the threat from anti-aircraft guns, surface-to-air missiles and enemy fighter aircraft were taken into account. Enemy defences were credited with the most technologically advanced systems which could be possible within the time-scale, so creating the worst possible defensive environment in which aircraft would have to operate. Simulated attacks were then flown against various counter-air targets, including dispersed aircraft, aircraft in revetments, shelters, and take-off and landing areas. Numerous interdiction targets were also modelled. A wide range of attack aircraft designs was studied, including some which were assumed to be future developments of existing types, such as Jaguar, Phantom, and Buccaneer. Among the new designs considered, some aircraft were assumed to have a swing wing configuration in order to exploit the extensive studies which had already been carried out on an Anglo-French variable geometry aircraft. Additionally, aircraft were endowed with a comprehensive range of avionic and electronic counter measure (ECM) equipment. The performance ascribed to these equipments took account of both the capabilities which were achievable at the time, and also likely future developments in the state of the art within the time frame under consideration.

2. In the computer programme, numerous tactical options were systematically studied, including defence saturation, penetration altitude, penetration speed and tactical routing, and the possible effects of fighter sweeps, fighter cover, and spoof and diversionary raids. It was assumed that ECM would be used extensively to jam both ground and airborne radars, and to decoy missiles, and a further important assumption was that attacking aircraft would employ terrain following radar to provide a night/all-weather capability. During these studies, all possible enemy defensive tactics were taken fully into account and, in each case, the potential enemy was attributed with the most effective tactics and defences which were likely to be devised.

3. Against this exacting and somewhat pessimistic scenario, the computer simulation provided the means with which to compare the operational profiles of the various aircraft designs under consideration. Beginning with the take-off phase, flights were processed through the cruise section to the Forward Edge of the Battle Area, followed by the high-speed dash to the target, the escape route back through the enemy defences, and the recovery to base. The different parameters mentioned created a vast number of permutations, which were comprehensively evaluated to assess different aircrafts' chances of success, each against the other. From this aircraft effectiveness data, and knowing how many weapons would be required to inflict a desired level of damage to targets, it could be calculated how many aircraft would be needed to reach the targets. On this basis, it was then possible to calculate how many aircraft of a given type would have to be launched on each raid. This whole process led to preliminary conclusions on force effectiveness, size and cost, and enabled first order cost effectiveness comparisons to be made between the various contending design options.

4. In order to minimise the total force numbers, and to cope with enhanced force numbers, there was a clear requirement for the aircraft to have a capability greater than that of existing types. In performance and equipment terms, this requirement was reflected in a need for an aircraft with a speed significantly exceeding that of the

Buccaneer, a much shorter take-off and landing performance than the Phantom or Buccaneer, and equipment for navigation and attack and ECM to give a penetration performance at least as good as a much improved Buccaneer.

5. At the time that these requirements were crystallising, the need for a replacement air defence fighter aircraft for the 1980s began to emerge. The output of the computer studies was available to provide some basis for performance calculations. In this context, both the speed and short-field performance parameters were already indicating the potential value of the swing wing concept. Gradually, as the study results were analysed, and the Fighter project began to take firmer shape, the possibility began to emerge that one aircraft, with some relatively minor alterations in baisc design, could meet the requirement of both the attack and fighter roles and could, indeed, probably satisfy the requirements of a wide number of traditional roles. From this complex matrix of seemingly conflicting needs, Tornado was born.

THE RAF AIR-TO-GROUND TASK

6. In recent years, there have been very considerable advances in air defence weaponry. In particular, the surface to air missile has introduced a high level of hazard to operations conducted in the high, middle, and low airspace. In response to this situation, the RAF has adopted low-level, high speed penetration as a key tactic to minimize acquisition by, and exposure to enemy defences. The low level profile makes the aircraft very much more difficult to detect and track on radar, and seriously degrades the effectiveness of most missiles. Moreover, sustained high speed penetration presents ground defences with an increased problem of faster reaction time. However, a low-level, high speed, profile is demanding and dangerous in terms of terrain avoidance, and places considerable demands on the aircraft's navigation and attack system, since at no time is either the pilot or navigator likely to see very far ahead of, or around the aircraft. Accordingly, not only must the aircraft's navigation and attack system be very accurate, but its sensors must be capable of rapidly updating the whole weapons system.

7. Should war break out in Europe, it is self evident that a rapid response to any enemy breakthrough would be vital. Such a response cannot wait for good weather conditions or, for that matter, for daylight. During winter, in some parts of Europe, it can be dark for some sixteen hours out of every twenty four, and it is well known that conditions of poor visibility, in daylight, can also exist for many days on end. It is equally well known that the potential enemy ground forces have the ability both to move, and to fight, in conditions of darkness and adverse weather. The RAF, therefore, considers it essential that its future strike/attack aircraft have the ability to operate effectively under these same conditions. Moreover, in terms of the attack phase of the sortie, the tactic of flying a "pop-up" manoeuvre in the target area, where pilots pull up to look for the target then follow through with a dive attack, must now be regarded as totally unacceptable. The probability is that important targets will be protected by a high concentration of very effective defensive systems. Accordingly, to reduce vulnerability, the entire process of target acquisition, identification and attack must, whenever possible, be carried out from low level altitudes, regardless of weather.

THE RAF AIR DEFENCE TASK

8. In very general terms, the air defence task involves maintaining the integrity of a designated airspace and denying the enemy freedom of action within that airspace. In the case of the United Kingdom, the Air Defence Region stretches from Iceland in the north, to the Channel in the south and from the Atlantic Approaches in the west, to the North Sea in the east. About 85% of the RAF's front-line air defence force is based within the UK itself and, given the enormous geographical area to be covered, the RAF sees an overriding need for a long range missile armed multi-purpose interceptor, with a good endurance performance. Although a high manoeuvre performance, matching that of any air superiority fighter, would be highly desirable in certain engagement situations - primarily in the context of fighter to fighter combat - this aspect, in combination with the essential criteria mentioned, would be extremely expensive to provide. In any case, the current and predicted threat against the UK Air Defence Region consists mainly of medium bombers. Accordingly, the primary task will be to destroy these bombers, rather than take on enemy fighters in close combat.

9. The RAF must be prepared for the enemy to employ mass-raid tactics in an attempt to saturate defences. Hence, our air defence aircraft must carry as many missiles as possible and, additionally, fire control systems must have the ability to engage a number of targets in rapid succession. The enemy has a number of attack options: he could employ high speed, low-level penetration tactics; penetrate supersonically at medium or high altitude; or he could coordinate attacks from all levels. Against this spectrum of threat, the RAF requires an advanced intercept radar and missile combination, which will allow the engagement of targets flying at heights either above or below the defending aircraft. This is commonly known as a "snap-up" and "snap-down" capability. Such a weapon system will also have to be highly resistant to the intensive ECM support which is likely to accompany enemy raids. Furthermore, it must be able to operate with the minimum assistance from ground control and early warning systems, as they themselves might be degraded by jamming. In meeting these requirements, it is important to achieve a fine balance between the strictly aerodynamic performance of the aircraft, and the overall capability of the weapon system as a whole. For example, there would seem little point in demanding a very rapid rate of climb, or an exceptionally high ceiling, from the aircraft if the same effect could be obtained, at less expense, by an

appropriate choice of missiles. As a final point for consideration, it would be totally unrealistic to imagine that an air defence system, however efficient one imagines it to be, will stop 100% of attacking forces from reaching their targets. The RAF expects that some airfields will sustain damage; therefore, it is essential that its air defence aircraft have a good short field performance to continue operations from airfields whose normal operating surfaces have been disrupted by enemy attacks.

TORNADO GR1 AND ITS ROLES

10. The first thing to realise about the Tornado GR1 Interdictor/Strike (IDS) aircraft is that it is a very small one. It compares in size with the F18, but is much smaller than either the F14 or F15, and its nearest comparable US counterpart, the F111. Its twin Turbo Union RB199 turbofans are located at the rear, with long variable intake ducts giving unobstructed flow from well forward of the shoulder-set variable geometry wings. From the cockpit, the pilots forward view over the nose is 15° down, while from the rear seat the occupant has a better field of vision than from the back seat of a Phantom. This has an added advantage for trainer versions since no external modification is required. Movement of the wings covers the range from 25° when fully forward to 68° when fully swept, with any intermediate selection being available. With the wings forward, the aircraft has a very long range and endurance capability, and the full-span leading edge slats and double slotted flaps allow low touch down speeds in the order of 110 knots (204 km/h). When combined with the use of thrust reversers on the engines, operations into 1000 m strips become feasible. Conversely, with the wings swept back, the aircraft can accelerate through the transonic regime into supersonic flight. Moreover, in this configuration the wing has a low gust response to provide essential stability for high speed, low-level penetration and attack. No ailerons are fitted; roll control is achieved by a differential movement of large tailerons, assisted at slower speeds by asymmetric deployment of spoilers from the upper surfaces of the wing. These spoilers also operate symmetrically after touchdown acting as lift dumpers. In line with many of today's modern combat aircraft, Tornado has a fly-by-wire system that transmits pilot commands to the control surfaces by electric signal. This innovation offers several advantages over the traditional mechanical/hydraulic system. To begin with, good steady state and dynamic responses to pilot demands are ensured under either high or low "g" conditions and the general ride characteristics are enhanced, particularly in severe turbulence at low altitude where a stable weapons delivery platform is most important. Stall, spin, and buffet characteristics are all improved and any automatic compensations for configuration changes are simplified. Finally, Autopilot Stability Augmentation and Terrain Following commands are more easily integrated into the system.

11. Tornado's engines have been designed to provide economic fuel consumption at dry settings during low-level transonic flight and also high reheat thrust for short take-off, combat, and Mach 2 plus flight. The remarkably small engine has a three spool layout, each independent of the other, which allows each section of the engine to run at its optimum speed without recourse to variable incidence blading. In size, the complete engine change unit is about 3.2 m long with a maximum diameter of only 0.85 m, including the afterburner. The reheat nozzle, which has overlapping petals, is fully variable to give maximum efficiency at part reheat settings. Fitted directly to the rear of the jet pipe, are clam-shell type thrust reversers, and reverse thrust can be used on the ground down to zero forward speed.

12. After the airframe and the power plants, the third part of Tornado's weapon system is the avionic equipment. Low-level, high-speed operations at night, in adverse weather conditions, and against jamming, are demanding at the best of times; they create a very exacting environment. For this reason the RAF considered that a two man crew was essential. Most, but not all, of the avionic management is conducted by the navigator in Tornado. The key to our intended low-level penetration tactics, in any weather, is the Texas Instruments' Terrain Following Radar system, similar in some respects, but more advanced, than the equipment in the USAF's F111s. Both manual and automatic modes can be flown at height selections ranging from 1500 feet (457 m) down to 200 feet (61 m) and a 'ride control' can vary the values of pull-up and push-over commands from the computer. Three qualities of ride control can be selected, with 'hard ride' giving the best terrain following performance at the expense of some discomfort to the crew. At the heart of the navigation and attack system, is a digital main computer, with a storage capacity roughly equal to that of a small commercial company's complete computer installation. This computer accepts, processes, and distributes information between the various peripheral equipments. In the rear cockpit, the navigator has two TV-tabulator displays, each with a multi-function key board through which he can communicate with the main computer. Basic attitude and velocity data for the crew is provided by an inertial navigator, doppler, and secondary attitude and heading reference systems. Navigation calculations are performed in the main computer, and the information is passed to both crew members, the weapon aiming circuits, and the automatic flight director system. The primary sensor of the avionics system is the ground mapping radar, optimised for air-to-ground use by utilising high technology features to give good resolution for mapping and target acquisition. As a target is approached, the main computer will point the pilot's head-up display (HUD) target marker, the ground mapping radar, and a laser range finder, all towards the estimated target position. Even in visual conditions, from low-level, the target might first be acquired on radar, and the whole system would then be updated by the navigator using a hand controller to place radar markers over the response. From this stage, a blind attack could be completed using the laser ranger to measure target depression angle for height computation. Should the pilot see the target, he could elect to

control the attack at any stage, using his own separate hand controller to position his HUD target marker directly on the target. This action further updates the computer with regard to pinpointing target position. Weapon release is cued by the main computer, provided that the pilot's weapon release button is pressed. A great deal of redundancy is built into the system, and no single failure, including that of the main computer, will prevent an attack being completed.

13. Armed with Tornado IDS, the RAF plans to exploit this comprehensive weapons system in a number of roles. These roles are aimed primarily towards fulfilling Britain's NATO commitments. This involves two spheres of operation, namely, overland in the Central Region and the Flanks of Allied Command Europe under SACEUR, and over the sea in the Eastern Atlantic and Channel, on behalf of SACLANT. In the overland case, the primary role in war is seen as counter-air operations against Warsaw Pact airfields, where the aim will be to frustrate and disrupt the enemy's operations by attacking his operating surfaces. An interdiction role will also be given to IDS Tornados, directed against Warsaw Pact lines of communication and support areas. There could also be a need to supplement the direct support of land forces by using Tornado GR1s in a close air support role; at present, the capability of European based ground attack aircraft is predominantly confined to daylight, fair-weather operations, but Tornado will be able to provide close air support, both at night and in poor weather conditions, thereby extending the RAF's overall capability in this role. A reconnaissance role is also planned for the aircraft and this will be a continuing task during all stages of any conflict, to provide quick and accurate intelligence information about enemy numbers, positions, and movements. A wide range of armament can be carried by IDS Tornados with some weapons being optimised for particular roles. Missiles can be carried for self-defence, and each IDS aircraft has a twin cannon installation, internally mounted, which can be used either for self-defence or, offensively, against ground forces.

THE TORNADO AIR DEFENCE VARIANT (ADV)

14. From the outset, two factors dominated RAF thinking on the new air defence aircraft. First, there was the need to capitalise on the large investments that were being made in the international Tornado programme and, of equal importance, there was the need to consider the special nature of the RAF air defence role, comprising both maritime and national air defence. For these reasons, and others already outlined earlier in this paper, the concept of a long range interceptor, rather than an air superiority fighter, was decided upon. Because of its engines and variable geometry wings the basic Tornado already possessed many of the characteristics required for such an interceptor and, in the interests of commonality, alterations to produce an air defence variant have been kept to a minimum. The main differences are the substitution of an air intercept radar, made by Marconi Elliot Aerospace Systems Ltd (MEASL), for the terrain following one in the IDS, and an extension of the fuselage to accommodate air-to-air missiles. To permit both front and rear hemisphere attacks the radar will have very good detection ranges, significantly better than current AIs can achieve, and also a look down mode against a background of terrain or sea clutter. Furthermore, it will have a track-while-scan facility so that multiple targets can be attacked in quick succession; here, the computer assists the crew by helping to determine attack-steering, and the most effective sequence of targets to select. Ground mapping and excellent short range performance are both built in features, and the Marconi equipment is versatile enough to cater for high crossing angle targets, or rear hemisphere attacks. As an integral part of this overall capability, the best possible Electronic Counter Counter Measures (ECCM) features have also been incorporated to enable continued operations in the inevitable ECM environment expected.

15. The standard weapon load which ADV will carry comprises a mix of missiles and a gun Sky Flash is the primary missile, which is a UK development of the American AIM7 Sparrow. Four of these will be carried, semi-submerged in recesses in the underside of the fuselage. These missiles, whose semi-active homing heads are of entirely UK design, have an improved snap-down capability, better descrimination against multiple targets, and much improved ECCM features. All of these facets are aimed at being particularly effective against the expected prime threat, a mass raid at low-level. Complementing the Sky Flash load, AIM9Ls, which are shorter range heat-seeking missiles, will also be carried. The internally mounted gun is a 27 mm Mauser cannon which has two selectable rates of fire and a remarkable muzzle velocity to give greatly extended firing ranges.

16. Although ADV's hardware is 80% common with the IDS version, the avionics system has been completely re-orientated to the air defence role in order to take full advantage of the advanced capability provided by the Marconi radar and Sky Flash. A completely new software suite has been introduced for the computing system, providing a large number of facilities to both the pilot and the navigator, to make the Tornado ADV several times more effective than existing air defence aircraft. Like any other air defence aircraft of even modest sophistication, the first problem to be solved is 'target identification'. No single foolproof system exists today, but the RAF believes in an approach which utilises a number of sensors. Clearly ADV's radar will help to locate targets and analyse their behaviour, and any response at 60,000 feet moving towards the UK at Mach 2.5 is unlikely to have friendly intentions. However, that is an extreme example so, as another measure, ADV will have an on-line ECM-resistant, netted data-link system. This will provide jam-resistant digital data transfer, secure speech, and precise navigation information. Within the data link community, will also be some ships, AEW Nimrod, and the UKADGE, together with the USAF and USN. ADV will also be fitted with an integrated IFF interrogator. Next there is a Visual Augmentation System, which is a built-in electro-optical device displaying a TV picture of the

target, allowing positive identification by day in sufficient time for front hemisphere firing. At night, and in starlight only conditions, the system will still allow identification at ranges well in excess of the required ranges for safe shadowing and missile release. Finally, a Radar Warning Receiver will be used, acting like an airborne electronic surveillance system. Its own computer will analyse any detected emitters to tell the crew what it believes the target-type to be, and from which direction it is approaching. Any specific threat to the aircraft itself, from SAMs or AI radars for example, will override the general surveillance mode, and trigger both audio and visual alarm warnings to the crew. All of these measures, in combination, will go a long way to resolving the problem of isolating friend from foe, with a high degree of assurance.

17. Given this wide range of equipment, the next question is how best to utilise all this capability. The navigator will have two TV tabular displays, like the IDS, from which he can call up several different formats at will. His basic working display will be a range/azimuth picture, incorporating track-while-scan, with a great number of targets shown at once and, if required, precise flight data shown on any one of them. Also available, are two types of pulse, raw velocity, ground mapping, fault read-out, navigation, and fixing formats. In the front cockpit, the pilot will have a HUD and, mounted beneath that, a single TV monitor. On this monitor, he can either elect to have one of the rear seat displays duplicated, or he can select his own attack display which will provide all the necessary information to complete a missile attack once a particular target has been selected. However, it is the HUD, common to all Tornados, which will be the pilot's main attack reference. Symbology for this fixed-combiner system, with a large field of view, has been specially adapted for the air defence role. In the not too distant future, it is hoped that a helmet mounted sight will be available to supplement the HUD, and the existing avionics in ADV have been designed for this eventuality. There is one other major display, quite revolutionary, called a Tactical Planning Format. On this, the crew will carry out their threat analysis, evaluate attack sequence options, and determine the best weapon alternatives. The display, which is North orientated, can show plan-view information including Combat Air Patrol points, Missile Engagement Zones, Airborne Early Warning barriers, as well as other co-operating fighters and the targets themselves. Complementing these normal modes of weapon and attack selection, the pilot also has an override system to enable him to enter a visual fight, should the situation arise. In this event, he can control all weapons without removing his hands from either the flying controls or the throttles.

18. In summary, Tornado ADV has a very flexible array of controls and displays to cope with a variety of engagement situations, from long range identification at one extreme, to close-quarters visual combat at the other. However, all of the computer-processed information is provided for advisory purposes only, and executive control of any action remains firmly with the crew. As an interceptor, the aircraft will be extremely effective in dealing with high or low-level attacks by medium bombers of the Fencer/Backfire type. Operating from ground alert, it will also be able to counter the type of stand-off missiles under development and, if launch-ranges of these are improved, Tornado ADV will have sufficient loiter capability to fly combat air patrols well out from the UK's coast-line. Similarly, for the maritime air defence role, combat air patrols, flown over the surface group to be protected, can meet the most serious threat of enemy aircraft carrying stand-off missiles.

SERVICING ASPECTS

19. There is little point in planning to operate an advanced weapons system without first making quite certain that it will be possible to maintain it. From the outset, Service maintenance experts have had a strong influence during the design stages to ensure that this objective is achieved. Consequently, all systems in Tornado are built on a Line Replaceable Unit basis, and there is a special maintenance panel on the aircraft to show the status of these units. Moreover, each unit has Built-In Test Equipment which enables it to be checked out quickly, and most have an external indication of their serviceability. The main computer also has a ground test programme which can be loaded to validate the whole avionics system. With the exception of a small number of items, maintenance is planned on a basis of replacing items only when they are shown to be defective. This scheme expends less time wasting in changing 'life-expired' parts, and encourages more economic use of parts in general. An automatic, computerised, diagnostic system, designed to check-out units and isolate faults, will also be available. All of these aspects should greatly assist in keeping periods of aircraft unserviceability to a minimum, and help to reduce aircraft turn-round times during war.

SUMMARY

20. The concept of producing a multi-role aircraft designed to meet the complexities of a number of roles was reached only after extensive computer analysis had shown the way ahead. For the RAF, the air-to-ground task and the air-to-air task calls for differing operating capabilities, but Tornado can meet these requirements. In its IDS version, the aircraft will be able effectively to carry out the roles of counter-air, interdiction, close air support, maritime attack, and reconnaissance. Moreover, it will be able to do so at very high speed and very low altitude, regardless of weather. The ADV, on the other hand, will use its powerful long range multi-target radar, advanced avionics with computerised mission planning, and automatic attack features, together with its missile armament, to make it the most effective interceptor available for the air defence of the UK's large strategic area. Backing this very wide range of capabilities, will be a comprehensive maintenance system of support, designed from the outset to optimise fault diagnosis, and keep the aircraft ready to fly with the minimum delay. The RAF has had

many distinguished aircraft in its service throughout the years, but the introduction of Tornado into front-line service will mark a significant increase in the RAF's fighting capability for both defensive and offensive operations.

LE SYSTEME D'ARMES DU MIRAGE 2000
INTERFACE HOMME MACHINE

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RESUME

Dans la fiche programme de l'Armée de l'Air française, le Mirage 2000, avion de combat monoplace doit être capable dans sa version de défense et de supériorité aérienne d'intercepter des appareils hostiles volant à très haute altitude, de détruire les avions ennemis pénétrant à basse altitude, d'engager le combat aérien rapproché à armes égales avec les meilleurs chasseurs de sa génération et doit être également en mesure d'accomplir des missions d'attaques au sol avec un armement conventionnel. Ce rôle polyvalent du Mirage 2000 a conduit les Services Techniques de l'Aéronautique et les Constructeurs à concevoir un système d'armes - navigation, pilote automatique, radar, conduite de tir, contre-mesures - très complexe. L'utilisation d'un tel système, qui poserait déjà un problème de saturation au pilote dans un avion de combat monoplace actuellement en service dans nos escadres, devrait être encore plus difficile dans le Mirage 2000. En effet, compte tenu des qualités de manoeuvrabilité de cet avion, largement augmentées par l'adoption de commandes de vol électriques, l'Armée de l'Air devra introduire de nouvelles tactiques de combat qui seront plus éprouvantes et plus contraignantes pour le pilote. Afin d'utiliser au mieux les grandes capacités opération nelles du Mirage 2000, un effort important d'intégration a été fait au niveau de la cabine pour réaliser les meilleurs compromis dans la présentation des paramètres et des commandes du système au pilote: visualisations tête haute adaptées à chaque phase de vol, commandes multiplexées, présentations synthétiques de situations tactiques.

1. INTRODUCTION

L'exposé se limitera au système d'armes du Mirage 2000 de défense aérienne. Dans le cadre de ce "36th AGARD Aerospace Medical Panel" il sera fait d'avantage dans l'optique d'une évaluation de charge de travail, de fatigue de l'équipage opérationnel en mission de combat, plutôt que dans celle d'une étude technique détaillée du matériel

La description du système sera donc assez complète dans ses principes mais sommaire dans sa réalisation et son fonctionnement, indépendamment des imprécisions volontaires qu'impose un exposé non classifié.

Le Mirage 2000 étant encore actuellement dans la phase essais en vol et non en escadre, cet exposé ne présentera donc qu'un état actuel du système qui est encore appelé à évoluer.

Nous verrons successivement:

- comment se présente le Mirage 2000 en mission opérationnelle en comparaison avec les avions existant actuellement dans les escadres de Chasse française;
- le déroulement de deux missions types du Mirage 2000;
- les systèmes principaux qui ont un impact direct sur la charge de travail de l'équipage. Nous ne parlerons pas, par exemple, des circuits hydrauliques, carburant, conditionnement ou encore de conduite moteur qui sont communs à d'autres avions et complètement assimilés, sans effort, par les pilotes.

Nous ne nous intéresserons qu'au SNA (Systèmes de Navigation et d'Armement) et au pilote automatique qui est l'aide au pilotage principal et indispensable à l'emploi opérationnel de l'avion.

2. LES OBJECTIFS DU MIRAGE 2000

Avant de parler des systèmes du Mirage 2000 de Défense aérienne, il est indispensable de rappeler brièvement quelques points importants concernant la mission, le domaine de vol, l'utilisation de l'avion. Cette première version du

Mirage 2000 a une vocation privilégiée de Défense et de supériorité aérienne. Il doit être capable d'intercepter des avions hostiles volant à très haute altitude, de détruire des avions pénétrant à basse altitude et d'engager le combat avec les meilleurs chasseurs de sa génération.

De plus cette version du Mirage 2000 doit être capable de missions secondaires telles que l'attaque au sol avec des armements variés mais conventionnels.

Pour répondre à ces besoins, le domaine de vol doit être au moins celui des avions de combat les plus performants et la direction du programme 2000 s'est fixée les valeurs suivantes:

- Mach 2,2 à haute altitude;
- 800 kts à basse altitude;
- un plafond pratique supérieur à 55000 ft avec deux missiles à longue portée;
- la possibilité de détruire un ennemi volant à 75,000 ft, Mach 2,5 moins de 5 minutes après le décollage.

Pour lui permettre d'engager le combat avec les meilleurs chasseurs de sa génération, on a été conduit à donner à l'avion une très grande manoeuvrabilité qui a été obtenue par l'introduction de commandes de vol électriques qui ont permis d'envisager de voler avec des marges statiques faibles voire négatives. Cette manoeuvrabilité se traduit bien sûr par des facteurs de charge importants, mais surtout par des changements de trajectoire rapides qui impliquent de brutales variations du facteur de charge, donc une fatigue plus importante et des conditions d'emploi des commandes des systèmes plus difficiles. Par exemple, par rapport aux avions existants actuellement dans l'Armée de l'Air française, le gain obtenu en facteur de charge maximum instantané est de 80% dans certaines parties du domaine; les facteurs de charge soutenus ont été améliorés d'environ 55% en subsonique et jusqu'à 130% à Mach 2.

Il faut également préciser que pour différentes raisons, économiques et politiques la formule monoplace a été retenue. Le pilote, seul membre d'équipage, a donc une charge de travail très importante qu'il doit effectuer souvent dans des conditions difficiles:

- difficiles physiquement en combat;
- difficiles également intellectuellement et matériellement car la mission principale doit se faire de jour comme de nuit, pratiquement indépendamment des conditions météorologiques.

Le pilote doit assurer la conduite de l'avion dans le respect des règles de sécurité des vols et de la circulation aérienne. Il doit mener à bien la mission de combat, c'est-à-dire détruire l'adversaire ou l'objectif au sol dans un environnement hostile. Le pilote doit à ce titre assurer sa sécurité contre l'ennemi (avions, engins) par sa vigilance et l'emploi des contre-mesures.

3. DEROULEMENT DE MISSIONS OPERATIONNELLES EN MIRAGE 2000

A titre d'exemple, pour illustrer le rôle et la charge de travail du pilote du Mirage 2000 nous allons le suivre au cours de deux missions d l'avion:

- une interception Air-Air
- une attaque au Sol après une navigation basse altitude en territoire hostile.

Chacune de ces deux missions peut comporter un ou plusieurs ravitaillements en vol.

3.1 Mission Air-Air

Le pilote après une période "d'alerte à temps" pour une mission de défense aérienne est passé en "alerte renforcée". Il se trouve donc dans l'avion, équipé de l'habit préssurisé pour la haute altitude. L'avion est armé avec missiles et canons. les sécurités sont enlevées, le système est en partie sous tension, le pilote a fait son inspection cabine, la centrale à inertie est alignée.

L'ordre de mise en route vient de lui être donné, le décollage aura lieu quelles que soient l'heure et les conditions météorologiques. Celui-ci intervient moins de deux minutes après réception de l'ordre. Le pilote en contact avec les OPERATIONS reçoit l'ordre de prendre un cap et une montée initiale pour intercepter des avions ennemis approchant à une altitude supérieure à 50,000 pieds et à un Mach légèrement supérieur à 2.

Le but de cette mission est la destruction de ces assaillants le plus rapidement possible pour réduire leur pénétration en territoire ami.

La manoeuvre sera donc, au moins dans un premier temps, une interception face à face avec des vitesses de rapprochement supérieures à Mach 3.

Peu après le décollage, l'avion est transféré a un centre de contrôle et de guidage radar (cellule d'interception) qui va guider le Mirage 2000 vers la cible en le plaçant dans les meilleures conditions, compte tenu de son armement. Plusieurs modes de transmission des ordres sont prévus dans le système d'armes du Mirage 2000.

Le paramètre TEMPS est primordial, le premier tir (celui des missiles longue portée), doit avoir lieu dans les cinq minutes qui suivent le décollage. Pour le pilote les contraintes physiques sont très grandes. l'avion monte en pleine charge post-combustion, l'accélération est importante, la pente de montée est très forte, le pilote est en vêtement pressurisé donc dans un environnement peu confortable. Sa tension nerveuse est grande, elle est celle de tout soldat partant au combat et c'est un paramètre à ne pas négliger.

La charge de travail est considérable pour un pilote seul.

L'interception comporte 5 phases pour lesquelles le pilote doit mettre en conditions le système d'armes tout en assurant la conduite de l'appareil:

- Phase de préguidage, tant que le radar n'est pas accroché, le pilote visualise les cibles, conduit l'interrogation IFF, initialise la poursuite; toutes ces informations sont présentées sur un écran tête basse:
- Phase de guidage.

  Le radar est en poursuite sur informations discontinues ou continues. Dans cette phase l'interception est présentée en situation tactique sur un écran tête basse, les informations sur la cible, les consignes et les ordres sont utilisables par le pilote en tête haute;
- Phase de tir qui a lieu dans le domaine du missile:
- Phase d'eclairement de la cible pour le guidage missile;
- Phase de dégagement, visualisée dans le viseur.

Ensuite dans le meilleur des cas, la mission est terminée, le pilote rejoint sa base et se pose

Mais il peut être amené à poursuivre la mission avec ses missiles courte portée et même ses canons. C'est alors une phase de combat plus ou moins longue avant le retour vers la base et l'atterrissage.

Le déroulement d'une telle mission est classique mais avec les avions les plus modernes existant actuellement, la tension imposée au pilote est de plus en plus grande:

- il lui faut réagir de plus en plus vite, mettre en oeuvre des systèmes de plus en plus complexes dans des temps de plus en plus réduits:
- il est amené à subir des contraintes physiques de plus en plus sévères (facteurs de charge plus grands et surtout variations beaucoup plus brutales du facteur de charge):
- les missions peuvent être de plus en plus longues avec le ravitaillement en vol;
- les conditions à l'atterrissage, avec l'abaissement des minima, peuvent également contribuer à augmenter la fatigue du pilote.

3.2 Mission Air-Sol

Dans une mission d'attaque Air-Sol les conditions sont différentes. L'avion est dans une autre configuration, il est beaucoup plus lourd. Le déroulement de la mission est entièrement du ressort du pilote qui sera souvent autonome sauf en mission d'appui au profit des troupes au Sol.

La préparation de la mission est plus longue, plus minutieuse, le déroulement souvent plus fatigant proximité du sol à grande vitesse (500 à 600 kt), turbulences, surveillance du ciel, emploi des contremesures . . . .

Le pilote est par contre dans une tenue de vol plus légère et plus confortable. La mission se déroule chronologiquement de la façon suivante:

– *Phase de navigation*

Elle se fait à une altitude et à une vitesse variables en fonction de la proximité de l'objectif. Elle peut comporter un ravitaillement en vol. Elle se termine de toutes façons à très basse hauteur et grande vitesse.

Elle se fait en autonome vers un point tournant, un point initial ou directement vers l'objectif Il est souvent nécessaire pour des raisons opérationnelles d'arriver sur l'objectif sur une route donnée à une heure donnée.

Cette navigation doit éventuellement être recalée avant la phase d'attaque.

– *Phase préattaque*

Elle est en fait une phase de présélection avant l'attaque. Elle se fait pendant la navigation. Le pilote doit choisir l'armement, le mode d'attaque et les conditions de tir.

– *Phase passage en attaque*

L'identification du point initial ou de l'objectif doit se faire en maintenant une très basse hauteur

Le pilote doit désigner le point initial ou directement l'objectif suivant le mode d'attaque sélectionné

– *Phase de tir.* de bombes lisses ou freinées, de roquettes ou aux canons.

– *Phase de dégagement* suivie à nouveau d'une phase de navigation en retour vers la base.

A tout moment le pilote doit être capable pour assurer la mission de faire des changements de navigation: zones de fortes concentration de DCA ennemie (Défense Contre Avions), par exemple, et d'effectuer des évasives en cas d'attaque par des chasseurs ennemis.

Le pilote doit également être capable d'engager le combat. Il abandonne la mission de bombardement, s'allège par largage des charges mais peut ainsi permettre à d'autres avions du raid de poursuivre leur mission d'attaque au sol.

Cette mission Air-Sol est aussi très compliquée, elle demande une concentration importante de la part du pilote dans des conditions de travail rendues de plus en plus difficiles par l'accroissement des moyens de défense au sol, en nombre et en performances, qui obligent le pilote à descendre de plus en plus bas, à des vitesses de plus en plus grandes.

Comme dans le cas de la mission Air-Air, après le tir, le pilote rejoint sa base, éventuellement après un ravitaillement en vol et doit être en mesure de poser son avion quelles que soient les conditions météorologiques et son état de fatigue.

4. PRINCIPE DE BASE DU SYSTEME D'ARMES DU MIRAGE 2000

4.1 Architecture Numerique

Le système d'armes du Mirage 2000 est évidemment très complexe. La caractéristique nouvelle essentielle est la numérisation du système. Elle permet d'assurer une grande capacité d'evolution et d'adaptation aux divers composants.

Cette technologie permet de relier les équipements par une liaison banalisée, le DIGIBUS (Fig 1) qui comporte une ligne de procédure et une ligne de données.

Ces échanges sont gérés par un calculateur principal qui est doublé, pour une fonction de gestion, d'une unité secondaire de gestion.

Outre le calculateur principal et l'unité secondaire de gestion, les équipements suivants sont reliés au DIGIBUS: centrale aérodynamique, centrale à inertie, poste de commande navigation, pilote automatique, radar et poste de commande radar, interrogateur-décodeur IFF, boitier générateur de symboles, poste de sélection d'armement, boitiers avion d'interface missiles, boitiers contre-mesures.

Sur le DIGIBUS, en plus des paramètres, sont échangées les informations concernant le bon fonctionnement des équipements. Les unités de gestion assurent ainsi une surveillance des fonctions du Système de Navigation et d'Armement (SNA) du Mirage 2000.

4.2 Visualisations Cathodiques et Commandes du Systéme

Le Mirage 2000 étant monoplace il fallait permettre une utilisation simple du système d'armes en mission opérationnelle, tout particulièrement en mission de défense aérienne.

Il a donc été nécessaire de procéder à l'intégration des visualisations et des commandes du système. Ainsi, bien que les capacités du Mirage 2000 soient beaucoup plus importantes que celles de très nombreux chasseurs, la cabine pilote (Fig.2) tout en restant assez chargée, est comparable à celles de ces mêmes chasseurs et l'emploi du SNA plus logique et plus aisé.

L'ensemble des informations de pilotage, de navigation et de conduite de tir est présenté sur trois visualisations cathodiques: (Fig.3)

– une tête de visée collimatée
– un écran tête basse;
– un écran contre-mesures.

Cet ensemble est piloté par un boitier générateur de SYMBOLES (BGS) qui génère les symboles à tracer, en balayage cavalier, sur les trois tubes cathodiques, tout en assurant la synchronisation nécessaire avec la vidéo TV qui parvient directement du radar à l'écran tête basse.

La réalisation du système d'armes a permis de ne présenter au cours de la mission que les informations strictement nécessaires à chaque phase de vol. C'est l'unité de gestion en service qui assure la gestion de la liste des informations à présenter à partir de la connaissance qu'elle a

– de l'état des postes de commande (sélection de modes)
– de l'état des fonctions du SNA (Surveillance des fonctions et modes dégradés).

La conception de l'architecture des commandes du système a été faite dans le but de simplifier au maximum la tâche du pilote.

La commande du système se fait par sélection d'une arme (Canon, Magic, Super 530 . . .) ou d'un mode (navigation, approche, rassemblement . . .). Cette sélection déclenche automatiquement la désignation des fonctions des divers équipements intervenant dans la conduite du tir ou le mode correspondant.

L'assistance au pilote peut-être encore complétée par la présélection automatique de sous-modes selon un choix préférentiel que le pilote peut modifier s'il le désire.

Le pilote dispose, au niveau des principales commandes, du compte rendu par voyants de la sélection effective des fonctions dans les équipements. Les informations en provenance des principales commandes sont acheminées par le DIGIBUS.

Certaines font simultanément l'objet de liaisons directes pour permettre l'utilisation de modes dégradés. Plusieurs de ces commandes sont multiplexées et ont une fonction spécifique selon la phase de vol.

Les commandes "Systèmes" (Fig.3) sont séparées en deux groupes:

– les commandes "temps réel";
– les postes de commandes.

Les commandes "temps réel" sont regroupées sur la manette des gaz et la poignée pilote. elles comprennent, en particulier, une sélection d'armes, Elles permettent au pilote le pilotage continu de l'avion tout en assurant l'utilisation du système d'armes.

Sur la manette des gaz (Fig.4) sont disposées les commandes suivantes:

- sélection d'armes à trois positions. canons, Magic ou renvoi au poste de commande armement pour les modes Navigation, Police du ciel, Super 530 et les fonctions Air-Sol une seule pression sur ce basculeur configure le Viseur, le Radar et l'Armement dans le cas du Canon et du Magic;
- commande marqueur radar;
- commande d'accrochage radar;
- commande de site de l'antenne radar;
- une commande qui a une fonction engin en Air-Air et une fonction d'allègement de symbologie en approche.
- une commande d'interrogation IFF en Air-Air et de sélection d'une deuxième pression de freinage pour maintenir l'avion au sol avec le moteur en plein gaz plus Post-combustion.

A ces commandes "Systèmes" il faut ajouter d'autres commandes qui sont également à "temps réel":

– commande aérofreins;
– phare de police;
– réarmement calculateur moteur.

Sur la poignée pilote (Fig.5) on trouve:

- la détente canons;
- la commande caméra de visée;
- le poussoir de tir Bombes, Roquettes, Missiles (BRM);
- un bouton à plusieurs positions qui commande:
  - le décrochage radar ou l'accrochage missile automatique en Air-Air,
  - une désignation d'objectif ou le passage Navigation/Attaque en Air-Sol;
- une command d'accrochage/Décrochage MAGIC;
- un alternat radio;
- une gachette de connexion/déconnexion de pilote automatique;
- une palette de mise hors service rapide du pilote automatique;
- une commande contre-mesures;
- une commande de TRIM (profondeur et gauchissement).

Les postes de commandes reliés au DIGIBUS sont les suivants:

– Radar
– Armement
– Navigation.

Bien que d'accès facile, comme le montre la Figure 3, ces postes de commandes sont utilisés pour des présélections au cours de phases de vol pendant lesquelles la charge de travail du pilote est moins importante. De plus, un MIP (Module d'Informations Programmables) introduit dans le PCN (Poste de Commande de Navigation) permet de charger rapidement la totalité du plan de vol de l'avion. La préparation du MIP s'effectue au sol pendant la préparation de la mission.

4.3 Maintenance Intégrée

Toute la surveillance et l'analyse de panne d'un tel système n'étant plus possible par le pilote, des circuits d'autotest ont été incorporés dans les équipements numériques et des surveillances internes dans les équipements analogiques. Seuls les résultats sont communiqués au pilote pour lui indiquer s'il peut ou non débuter ou poursuivre sa mission dans les conditions prévues.

Ces moyens intégrés peuvent être utilisés pour la maintenance au sol par:

- la mémorisation en vol des résultats d'autotests mauvais;
- le traitement logique différé de ces mémorisations et visualisations;
- le déclenchement de séquences particulières d'autotests.

5. FONCTIONS ET COMPOSANTS PRINCIPAUX DU SYSTEME D'ARMES DU MIRAGE 2000

5.1 Pilotage

Le pilotage de l'avion est assuré:

- soit manuellement;
- soit automatiquement par le pilote automatique.

Les informations nécessaires sont élaborées par l'ensemble aérodynamique, la centrale à inertie.

Le pilotage manuel ou automatique est un pilotage en trajectoire.

5.1.1 Présentation des Paramètres

L'utilisation des tubes cathodiques a permis de faire du VISEUR VE 130 l'instrument principal de pilotage. On peut en effet présenter des symbologies complètes utilisant les concepts modernes: vecteur vitesse, pente potentielle, piste synthétique.

En plus de ces paramètres les informations suivantes sont visualisées:

- horizon;
- cap magnétique synthétique ou cap vrai;
- altitude barométrique et radiosonde;
- vitesse conventionnelle et Mach.

L'horizon et le cap de la centrale à inertie sont recopiés sur un indicateur sphérique. Le cap gyromagnetique ou vrai est également visualisé sur l'indicateur de navigation. Les autres indicateurs de la planche de bord sont essentiellement des instruments de secours:

- horizon de secours;
- anémomachmètre pneumatique;
- variomètre pneumatique;
- compas de secours;

auxquels il convient d'ajouter un indicateur d'incidence, un accéléromètre et un chronomètre.

5.1.2 Pilote Automatique

Le pilote automatique est l'aide indispensable du pilote. Sans lui l'utilisation du système d'armes ne peut être que partielle. Il dispose de deux modes de base:

- maintien de l'inclinaison en virage si celle-ci est supérieure à 10° à la connexion, ou de la route dans le cas contraire;
- maintien de la pente actuelle.

Afin de permettre au pilote l'utilisation du pilote automatique pendant les phases de préparation au combat, la modification des références de pente ou de route est obtenue à partir du bouton de trim de profondeur et de gauchissement sur la poignée pilote. Le poste de commande permet la mise en service ou hors service du pilote automatique mais une palette, intégrée au pied de la poignée de manche, permet sa mise hors service rapide par le pilote.

Les modes supérieurs du pilote automatique sont actuellement: capture et maintien de l'altitude au passage ou d'une altitude présélectée, atterrissage en catégorie 2 et navigation inertielle. La sélection de ces modes se fait sur le poste de commande.

5.2 Fonction Navigation et Approche

La navigation de base du Mirage 2000 est autonome. Elle est élaborée à partir des informations fournies par le système inertiel qui permet:

– la navigation vers un but affiché;
– la navigation suivant une route affichée;
– l'arrivée sur le but à une heure désirée affichée.
– le recalage de la navigation.

Les informations des moyens de radionavigation (VOR/ILS, MARKER, TACAN) sont utilisées dans certaines phases de vol ainsi qu'en navigation secours.

Les informations de navigation autonomes sont présentées:

– sur le poste de commande navigation (Fig.6)
– sur l'indicateur de navigation;
– sur la tête de visée en mode NAVIGATION (Fig.7)
– sur l'écran multimodes tête basse en mode NAVIGATION.

L'approche est réalisée:

En mode normal

A l'aide d'informations présentées sur la tête de visée après sélection du mode "approche" par le pilote.

Cette visualisation permet d'effectuer:

– l'approche à vue
– l'approche guidée GCA;
– l'approche avec guidage ILS (Fig.8)
– le contrôle de l'approche au pilote automatique couplé à l'ILS.

Le poste de commande navigation permet dans le cas de l'approche, en plus des informations liées à la navigation:

– le cap vrai de la piste;
– la pente d'approche désirée;
– la pente du faisceau glide.

En mode secours

A l'aide des aiguilles croisées de l'indicateur sphérique en approche ILS, ce qui est le moyen de base de la plupart des avions existants.

En mode automatique

A l'aide du pilote automatique qui est, dans ce cas, couplé à cette fonction. Le fonctionnement est alors contrôlé par le pilote à partir de la visualisation tête haute ou de l'indicateur sphérique en cas de panne de celle-ci.

5.3 Fonctions Air-Air

La mission de Défense aérienne du Mirage 2000 repose sur les possibilités suivantes:

– interception guidée par le sol. Le chasseur reçoit des informations sur l'hostile et des consignes pour l'intercepter;
– interception orientée. le chasseur reçoit des informations moins complètes et conduit luimême l'interception jusqu'à l'accrochage du radar de tir;
– interception à la découverte: Le chasseur est autonome;
– combat
– police du ciel. Le chasseur rassemble sur un avion détecté non identifié pour en vérifier l'identification.

Ces missions sont réalisées avec les équipements suivants:

– le radar;
– l'interrogateur IFF;
– la visualisation tête basse (Fig.9);
– la visualisation tête haute;
– les moyens radio.

Pour mener à bien les missions Air-Air le pilote a à sa disposition les commandes suivantes:

Commandes "à temps" de présélection et de préparation

- Le PCA (Poste de Commande Armement) (Fig.10);
- Le PPA (Poste de Préparation Armement) (Fig.11);
- Le PCR (Poste de Commande Radar) (Fig.12).

Commandes "temps réel" situées sur:

- le manche pilote;
- la manette des gaz.

L'exécution de ces missions et le pilotage, comme pour la navigation et l'approche, sont conduits à l'aide des visualisations tête basse et tête haute.

Les différentes fonctions Air-Air sont le résultat d'une sélection, par le pilote, d'un armement. On peut citer les modes suivants:

- mode SUPER 530
- mode MAGIC
- mode Canons AIR-AIR
- mode Police du ciel.

A chacune de ces sélections correspond une figuration viseur, une loi de navigation adaptée pour amener l'avion dans les meilleures conditions pour un tir ou pour une identification.

5.4 Fonctions Air-Sol

Conformément à la fiche programme, le système d'armes du Mirage 2000 permet d'effectuer des missions d'attaque Air-Sol avec des armements classiques: canons, roquettes, bombes lisses et bombes freinées non nucléaires.

Ces missions sont secondaires pour le Mirage 2000 de Défense aérienne. Seul le tir des bombes lisses est automatique par calcul continu du point de largage (CCPL).

Pour les autres armements le tir est manuel mais le point d'impact calculé en permanence par le système est présenté dans le viseur (CCPI).

Deux types d'attaque sont prévus dans la conduite de tir Air-Sol:

- l'attaque directe concernant tous les armements où la désignation se fait sur l'objectif;
- l'attaque avec point initial uniquement pour les bombes lisses et les bombes freinées.

La désignation se fait sur le point initial. Celle-ci initialise automatiquement la phase prétir et tir et présente dans le viseur la symbologie nécessaire au pilotage jusqu'à l'instant du tir.

Le capteur de désignation est le Radar en fonction télémètrie Air-Sol.

Ces deux types d'attaque comportent:

- une phase de navigation;
- une phase d'attaque.

La préparation de la phase d'attaque se fait pendant la navigation à l'aide des postes de commandes armements et Radar. Le pilote peut à tout moment en vérifier la bonne sélection et l'état satisfaisant du système.

Le passage en figuration attaque se fait à l'aide d'une commande "à temps réel" située sur la poignée pilote.

A tout moment, avec le même bouton, le pilote peut avoir en tête haute soit la symbologie Attaque, soit la symbologie Navigation que nous avons déjà présentée. Il y a mémorisation de la présélection.

Dans ces missions le système inertiel permet la Navigation vers le but, une base additionnelle ou point initial introduit dans le système avant ou pendant le vol.

Il permet également le recalage sur un point dont les coordonnées sont connues et permet la validation d'un recalage par télémètrie radar.

Nous verrons ultérieurement le rôle du Radar dans les missions AIR-SOL.

En mode attaque, le viseur présente différents symboles selon la présélection de l'arme.

On peut citer les réticules suivants en plus des réticules généraux: horizon, cap, moquette, altitude, vitesse/Mach, hauteur ... hauteur de garde.

En bombes lisses

- réticule de désignation;
- réticule armement;
- une barre de désignation.

En bombes freinées

- une ligne de chute des bombes avec point d'impact de la dernière bombe de la salve;
- un réticule et une barre de désignation dans le cas du tir avec point initial

En canons et roquettes

- réticule de visée;
- domaine de tir;
- barre de sécurité;
- croix de dégagement.

Les commandes (préparation et "temps réel") sont prises parmi celles des fonctions Air-Air grâce au multiplexage des commandes.

5.5 Le Radar et son Rôle dans les Fonctions NAVIGATION, AIR-AIR et AIR-SOL

5.5.1 Le Radar

Deux radars sont prévus pour la version actuelle, un troisième pour la version pénétration volera dans un an environ. Le premier Radar étudié pour équiper les Mirage 2000 est le RDI (Radar Doppler à Impulsions) qui permet en mission Air-Air la détection et la poursuite de cibles à Haute, Moyenne et Basse altitude. Optimisé pour l'interception à toutes altitude, il dispose en plus des modes de détection, poursuite et guidage, d'un mode de visualisation du sol. Le RDI est un radar Doppler à haute fréquence de récurrence. Travaillant en bande X, il utilise une antenne plate avec aérien IFF intégré.

Le deuxième radar proposé pour le Mirage 2000 est le RDM (Radar Doppler Multirôle). Le RDM reprend la structure générale du RDI; Comme le RDI, il est modulaire, il possède un émetteur cohérent, il est organisé autour d'un illuminateur à onde continue.

En revanche, il est équipé d'une antenne du type Cassegrain inversé et il permet, avec de bonnes performances, d'accomplir des missions très variées: interception à toutes altitudes, pénétration et attaque au sol et en mer.

Le Poste de Commande Radar en cabine (PCR) permet la commande du fonctioneement du radar, assure le codage et la mise en série des informations nécessaires en provenance des commandes "temps réel" situées sur la manette des gaz et la poignée de manche.

5.5.2 Fonctions du Radar en Mission AIR-AIR

Le Radar assure:

- la détection en recherche des échos avions désignés;
- la poursuite automatique du but qui est faite soit sur informations discontinues (PSID) avec recherche d'autres cibles, soit sur informations continues (PSIC) donc avec asservissement de l'antenne sur la cible désignée.
- l'accrochage automatique dans l'axe;
- l'illumination du but pendant le tir d'un missile Super 530.

L'interrogateur IFF intégré au RDI permet l'identification des cibles détectées par le radar au cours de l'interrogation. Celle-ci est effectuée à la demande du pilote par une commande "en temps réel" placée sur la manette des gaz.

Dans tous les modes de poursuite, le radar délivre des informations sur la cible (direction, distance, vecteur vitesse, vitesse de rapprochement et éventuellement le facteur de charge). Il effectue des calculs de domaine de tir et de lois de navigation optimisées pour chaque arme sélectionnée.

L'acquisition de la cible est réalisée à l'aide de la visualisation tête basse qui présente une situation sur un balayage du type B ou du type PPI.

En plus des informations sur le but, la visualisation tête basse présente des consignes pour le chasseur: Mach, altitude à prendre, directeur d'ordres, domaine, dégagement . . . (Fig. 15).

Après l'accrochage radar, l'interception est poursuivie à l'aide de la visualisation tête haute. Elle présente en plus des informations de pilotage:

– des informations sur la cible:
  carré but, vitesse de rapprochement, altitude, Mach, distance;
– des informations sur la domaine de tir, l'état de l'armement;
– des valeurs de consignes: Mach, altitude, route.

En fonction combat des informations pour le MAGIC et des réticules liés aux canons:

– direction moyenne des armes;
– ligne de traceurs (CCLT) (Calcul Continu de la Ligne de Traceurs);
– réticule de tir;
– distance nominale de tir et domaine.

5.5.3 Fonctions du Radar en Mission AIR-SOL

En mission Air-Sol le radar est normalement utilisé dans trois modes:

– Télémètrie Air-Sol.
  Dans ce mode le radar mesure la distance oblique Avion/Sol selon l'axe radioélectrique de l'antenne du radar positionné par le système de NAVIGATION et d'ATTAQUE. Cette télemètrie permet:
  – le recalage de position en navigation;
  – le désignation et la mesure de distance en phase d'attaque.

– Visualisation du sol.
  Dans ce mode spécifique de la navigation la visualisation tête basse présente au pilote une carte des échos du sol.

– Découpe isoaltitude.
  Dans ce mode, utilisé en navigation basse altitude, le radar visualise les échos différemment selon leur situation en hauteur par rapport à un plan situé sous l'avion (hauteur de garde) affiché par le pilote

6. CONCLUSION

La fiche programme du Mirage 2000 était ambitieuse.

Le choix de la formule monoplace dictée par le contexte économique et politique de la France a conduit à envisager un avion particulièrement étudié, tant sur le plan structure, motorisation et commandes de vól que sur celui du système d'armes.

Une telle complexité du système ne pouvait être envisagée:

– sur le plan technique, que par la numérisation des équipements et l'utilisation d'un DIGIBUS pour en permettre le dialogue;
– sur le plan utilisation par un seul membre d'équipage, que par l'optimisation d'une intégration complète des moyens de visualisation et de mise en oeuvre qui a conduit à un multiplexage de plusieurs commandes.

Un problème reste à résoudre, qui n'est pas de la seule compétence des techniciens, c'est celui du comportement du pilote:

– en temps de guerre: fatigue et capacité de récupération;
– en temps de paix critère de recrutement, entraînement, contrôle . . .

autant de questions que doivent se poser les spécialistes de la médecine aéronautique.

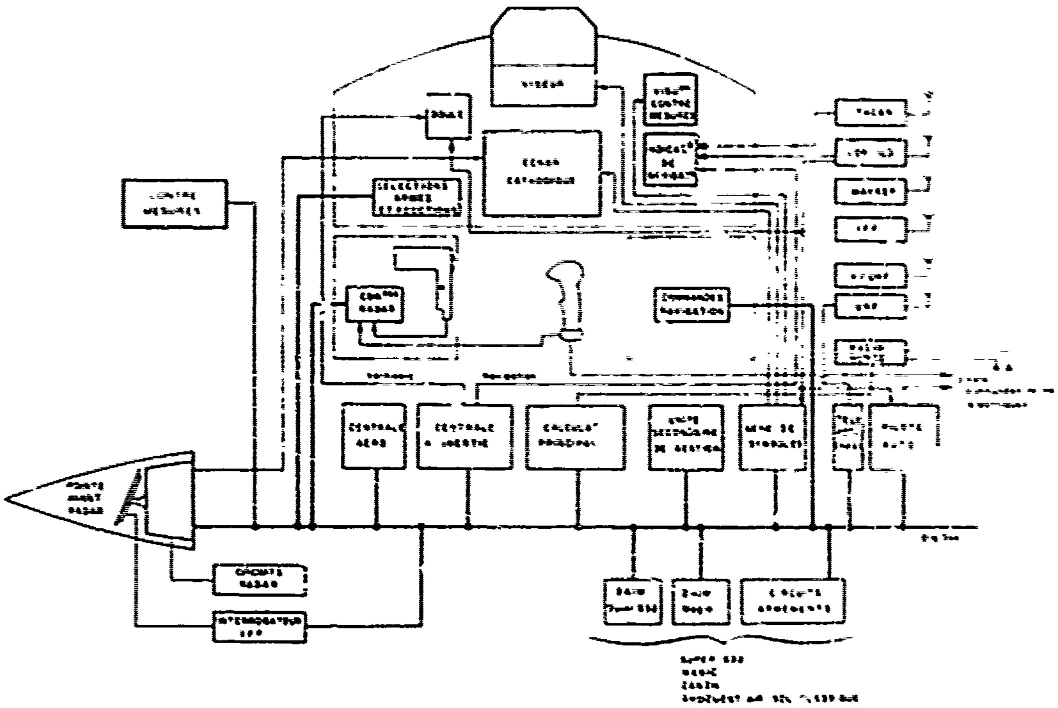


Fig.1 Système de navigation et d'armement

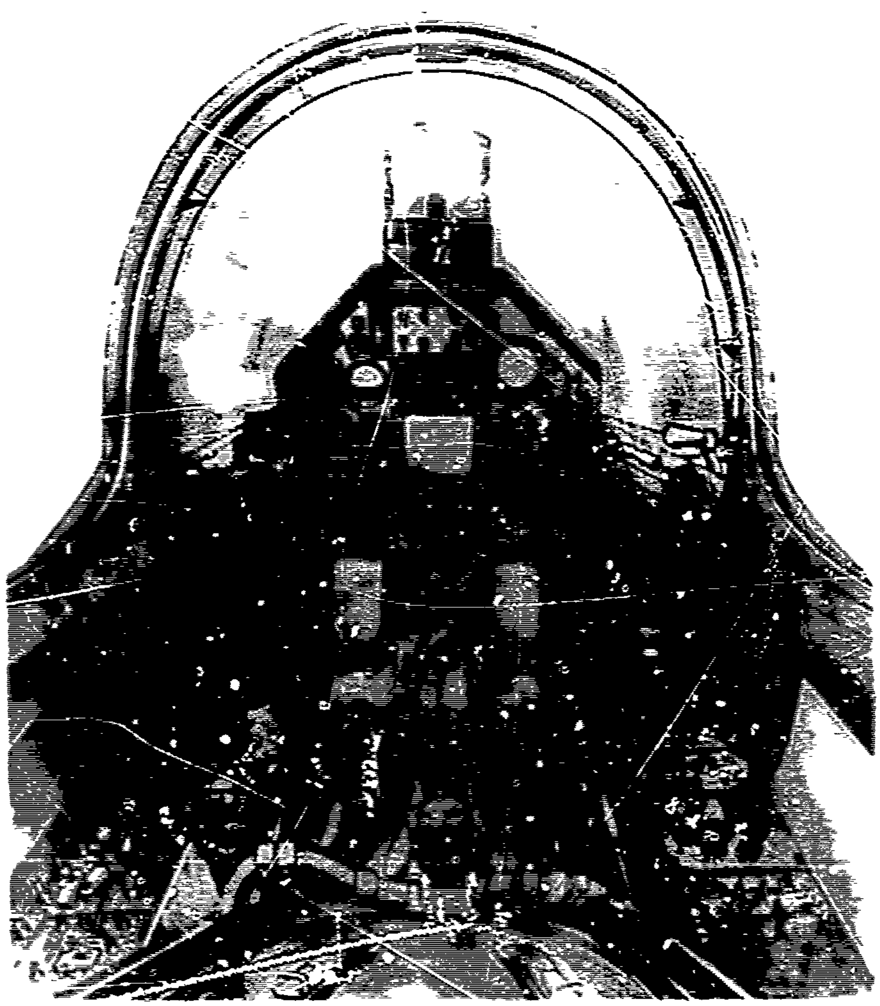


Fig.2 Cabine pilote

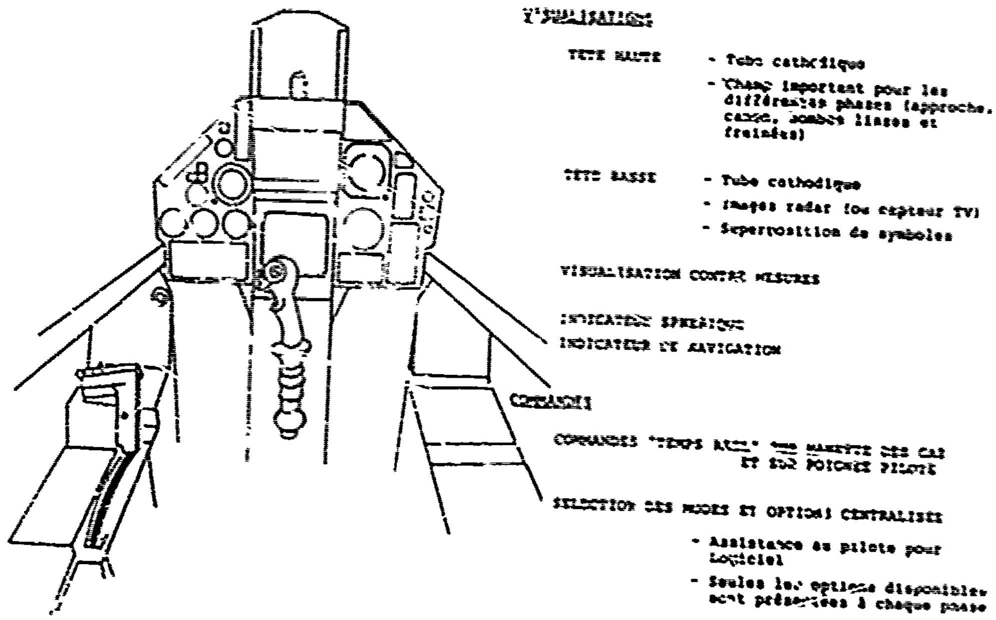


Fig.3 Visualisations et commandes

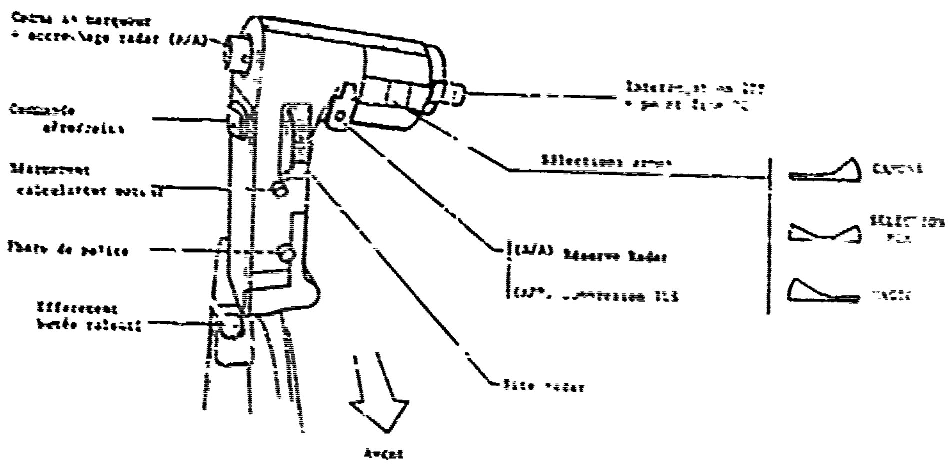


Fig.4 Manette des gaz

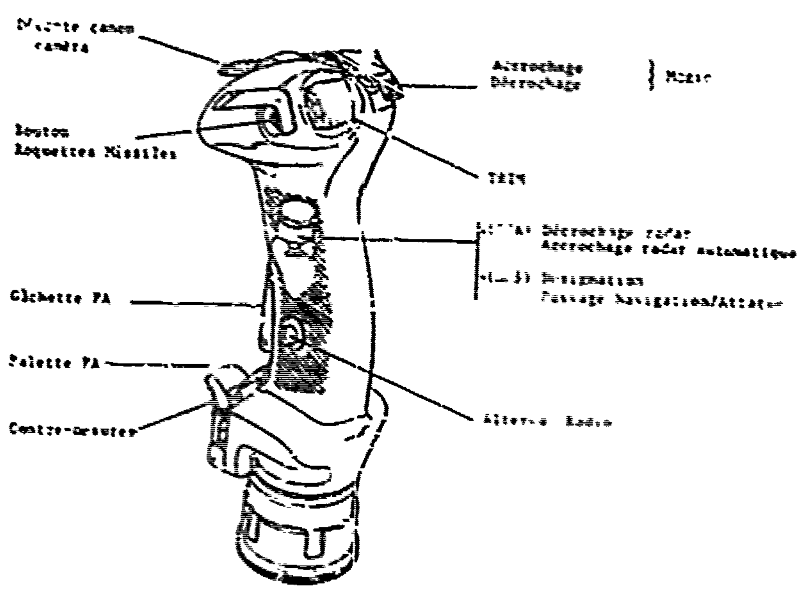


Fig.5 Poignée pilote

UNI 52 MIRAGE 2000

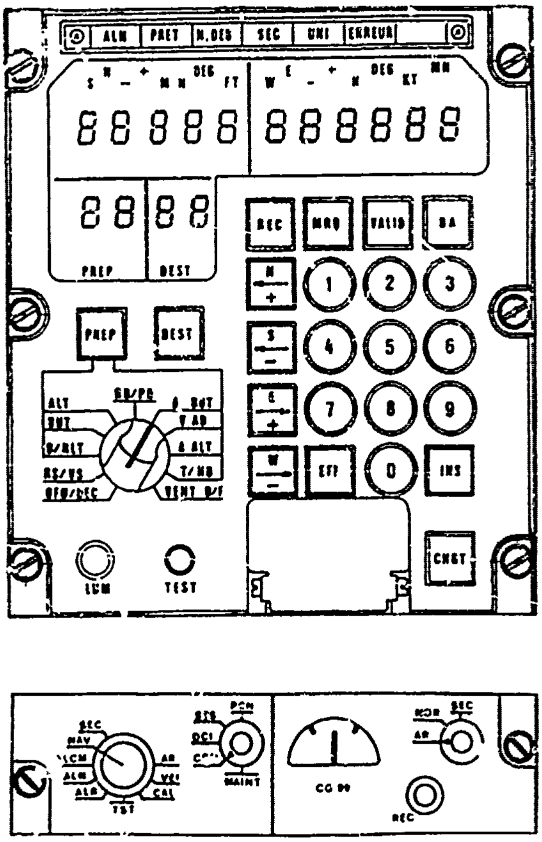
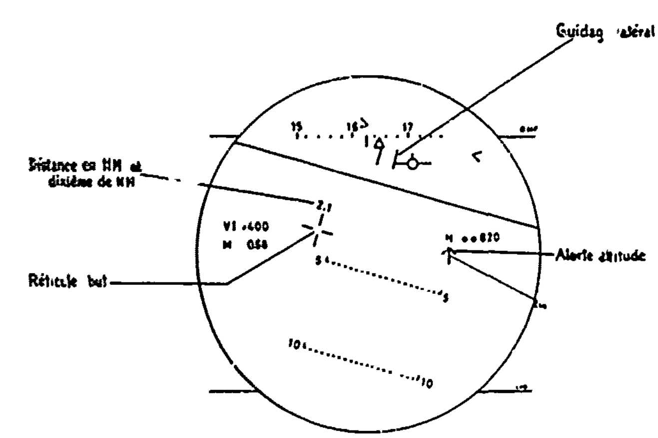


Fig.6 Postes commande de navigation

FONCTION NAVIGATION

Visualisations



Commentaires

Le pilote est averti :

. que l'avion a atteint la hauteur de décision (par la flèche clignotante ↑)

. que l'avion est en accélération longitudinale

. qu'il doit virer à gauche pour arriver vers le but sur la route désirée

Fig.7 Fonction navigation – visualisations

VE 130 M 2000

APPROCHE AVEC ILS
ET H RADIO < HG
ET SELECTION HRS

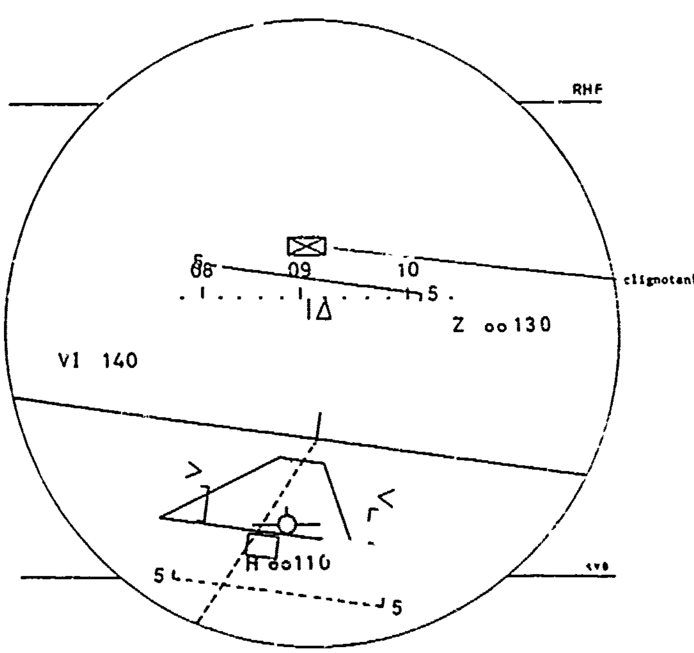


Fig.8 Viseur en fonction approche avec ILS

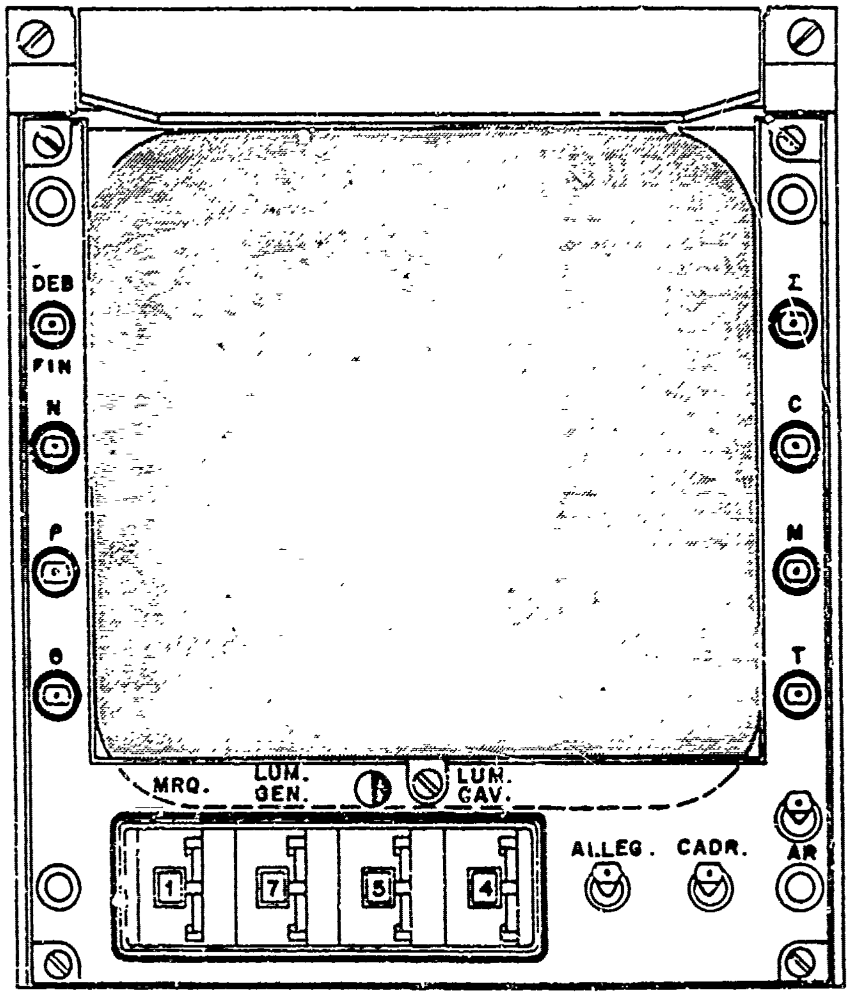


Fig.9 Module écran tête basse

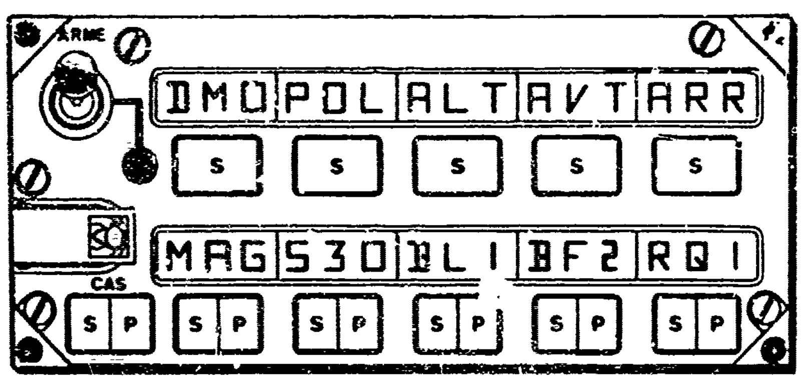


Fig.10 Poste de commande armement

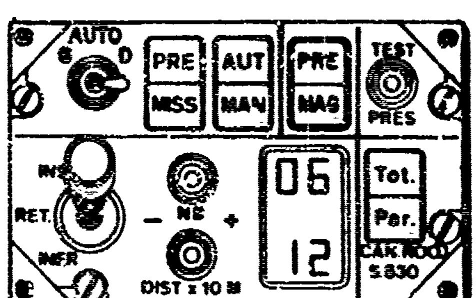


Fig.11 Poste de preparation armement

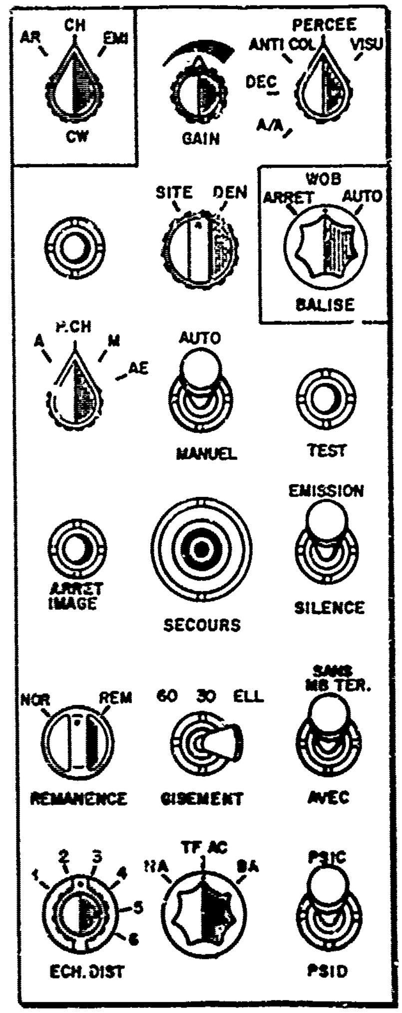


Fig.12 Poste de commande radar

Présentation type PPI

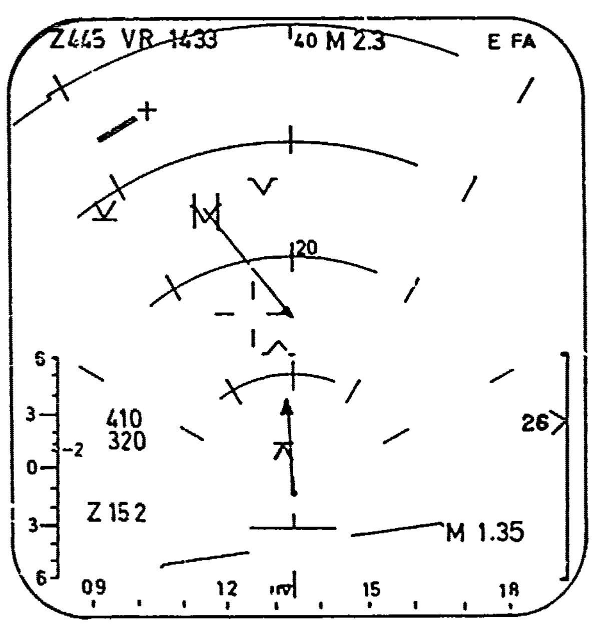


Fig.13 Radar en PSID
Sans objectif désigné
Ni introduction de données

TORNADO - AIRCREW SYSTEMS

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INTRODUCTION

The operational roles of Tornado - formerly known as the Multi-Role Combat Aircraft (MRCA) - have been described in some detail in the previous paper. The combination of these roles in a single aircraft dictated a number of simultaneous but sometimes contrasting requirements to be addressed in the design of various aircrew systems and personal equipment. As a multi-national project between the UK, Germany and Italy it was also obviously desirable to strive for commonality and to avoid a proliferation of individual national alternative requirements.

Tornado has been fortunate in this respect, particularly because the membership of participating nations has remained unchanged since the time when the requirements were finalised. During the Project Definition Phase a UK Working Party was set up which considered in detail all aspects of the aircrew equipment assembly (AEA) for Tornado including the cabin environment, the escape system, personal equipment and associated supply systems, and survival equipment. The report of the Working Party formed the basis of discussions between the manufacturer PANAVIA, NAMMA (NATO MRCA Development and Production Management Agency) and UK service and government departments and it was adopted as a statement of official UK policy in relation to design, development and production in these areas. Finally the proposals made in the report were discussed and formally accepted by the tri-National NAMMA Cockpit Coordination Committee.

The concept of commonality of the aircrew systems in the aircraft, irrespective of their national destination, thus was established from the outset. This agreement had the further advantage that it allowed National freedom in the choice of items comprising the AEA (ie aircrew flying clothing and personal equipment carried on the man) provided that it was compatible with the interface at the ejection seat.

Throughout the development of the aircraft the coordination of aeromedical advice has been the responsibility of the Royal Air Force Institute of Aviation Medicine which has also been responsible for demonstrating, on the behalf of the three Nations, the satisfactory integration and functional compatibility between the man, his equipment, the ejection seat and the cockpit. For this purpose an accurate wooden mock-up of the Tornado cockpit was constructed early in the Project Definition Phase and this has been in use continuously since then for running assessments during development of the ejection seat and items of the AEA etc. Finally, earlier this year, the mock-up and fully representative Type 10A seat were used for a trial involving one hundred aircrew who were selected to span the anthropometric range of aircrew size. The purpose of this trial was to validate the size rolls and integration of preproduction standard items comprising the various AEA's, to identify any unforeseen man/seat/cockpit incompatibilities, to define any limitations to be imposed on the aircrew population acceptable for Tornado on account of critical anthropometric dimensions and to refine proposed aircrew drills for strapping-in, emergency ground egress etc.

No attempt is made in this paper to consider each and every aircrew system in detail, instead attention will be focussed on more novel systems especially where useful comment can be made from experience gained during laboratory assessments or from flight trials.

COCKPIT ANTHROPOMETRIC REQUIREMENTS

It was agreed by the three Nations that Tornado should accept the range of aircrew from the 3rd to the 99th percentiles relating to seven anthropometric variables quoted by Samuel and Smith in 1965 (1) but referring to an earlier unpublished survey by Morant in 1955. Later, more comprehensive and up-to-date anthropometric tables became available with the publication of the 1970/1971 Survey of 2000 RAF Aircrew (2). Comparison of the tables of sitting heights shows that the 3rd percentile sitting height in the 1955 survey is equivalent to the 1st percentile in the 1970/1971 Survey (34.04 in, 864.7 mm). The Type 10A ejection seat in Tornado is installed with the ejection gun and seat rails inclined at 20° back from the vertical. In addition to ±72 mm seat pan height adjustment about the seat reference point to accommodate the 1st - 99th percentiles of the present aircrew population, an extra 34 mm upward travel has been provided in order to provide optimum forward vision for an instructor pilot when the seat is mounted in the rear cockpit of the training version of the aircraft. However, because the seat back profile rotates the occupant forwards, so that he is sitting at approximately 12° rather than 20° inclination, the effect is to raise the level of his eyes still further. Thus the full 34 mm of additional upward seat pan travel, which is available on all seats, is not strictly necessary and provided that it does not introduce an individual limitation for reach, it can be used to accommodate aircrew who are even shorter than the 1st percentile sitting height. With the seat pan adjusted to the fully down position the upper limit of 99 percentile height is determined by the datum line for viewing the Head-Up Display (HUD). During the 100 aircrew trial it was shown that when the eyes are at this plane there is still approximately 100 mm (3.9 in) clearance between the pilot's helmet and the cockpit canopy and that this clearance is not materially affected (±5 mm) by the type of helmet worn nor whether the helmet visor is up or down. Thus if the HUD can be satisfactorily viewed from above the datum line it will be possible to accommodate aircrew with sitting heights greater than the 99th percentile. The rudder pedals are provided with 190.5 mm (7.5 in) adjustment in the fore-and-aft plane and their position relative to the seat reference point takes into account the rearward movement of the seat pan as its position is adjusted upwards. When adjusted fully forwards total rudder pedal movement is 161.0 mm (6.3 in), this is reduced to 144.0 mm (5.7 in) when adjusted fully rearwards.

It was shown during the trial that no special anthropometric limitations for variables such as buttock-knee length, buttock-heel length, reach etc will be necessary either to allow the full range of cockpit activities or to ensure freedom from contact with cockpit structures during ejection.

CABIN PRESSURISATION, CONDITIONING AND COMMUNICATIONS SYSTEM

The cabin pressurisation schedule adopted for Tornado is that pressurisation commences at 5000 ft, between 5000 ft and 40,000 ft it is linearly related to the atmospheric pressure and above 40,000 ft it is maintained at a differential of 5.25 $lb.in^{-2}$. In association with the oxygen system (described below) this takes into account the various factors of structural strength and weight penalty, the prevention of hypoxia, decompression sickness and otitic barotrauma and the effects of rapid decompression discussed by Ernsting (3) in support of this schedule.

The design of the cabin conditioning system aims to provide a mean cabin air temperature (DB) in the vicinity of the aircrew such that thermal comfort will be achieved by maintaining a mean skin temperature of 33°C. This requires the cockpit temperature to be controllable between 15°C and 35°C under all conditions. Particular attention has been paid to the design of the cabin air flow distribution system which distributes incoming air not only at feet and waist level but, more importantly for comfort, around the head and shoulders. The air for head cooling is distributed through ducts in the ejection seat head box. However, calculations by Allen (4) of the total cabin heat load, available air flow and cabin inlet temperatures indicate that these conditions will not be fully met under the most severe combinations of altitude, speed and solar radiation. Needless to say, this is a universal problem and it is not specific to Tornado in any way. Improved conditioning would almost certainly be at the expense of a degradation in engine performance and an increase in the present cabin noise to an unacceptable level. While it is anticipated that the present system in Tornado will represent a genuine improvement over previous aircraft, a fall-back option employing a personal closed-circuit liquid conditioned suit system (5) has been maintained. Apart from requiring modest electrical power this system is independent of other aircraft systems and for use in an NBC environment has the added attraction that unlike air ventilated systems it does not require decontamination of the air supply.

The aircraft communications system has been designed for compatibility with both high and low impedance mic/tel systems. This permits considerable latitude in the freedom of National choice of oxygen masks and protective helmets. However, since the Tornado Tri-national Training Establishment will almost certainly operate with aircrew wearing a mix of national helmets with different impedances (eg UK Mk 4 and US or French helmets) the system has been modified so that it will accept differences in impedance between the helmets used simultaneously in the front and rear cockpits.

G-PROTECTION SYSTEM

G-protection is provided by the use of anti-G suits inflated with engine bleed air via a G-sensitive valve. Suitable anti-G suits, which have a nominal 3 litre capacity at zero gauge pressure and 10 litre capacity at 5 $lb.in^{-2}$ (34.5 kPa) gauge, include the UK internally worn Mark 6 and externally worn Mark 2 and the US CSU/3P suits. Connection between the anti-G suit and the inflation system is via the Personal Equipment Connector (PEC) on the ejection seat. The inflation profile provided by the anti-G valve is identical with that in Hawk, Jaguar and Lightning having a cut-in at 1.75-2.25 G and a high pressure gradient relating suit pressure and acceleration such that suit pressure = (1.25G-1) $lb.in^{-2}$. The disadvantage of this schedule, while it provides good protection when acceleration is sustained, is in the response to transient peaks of acceleration above the threshold level which some aircrew find distracting. Thus for the IDS version of the aircraft an alternative profile has been suggested which will "smooth out" the initial response of the valve to +Gz. This modified schedule is in the interest of aircrew preference and comfort rather than necessity since early flight experience suggests that Tornado is notably stable and free from buffet at low level and high speed.

OXYGEN SYSTEM

With the introduction of the Type 10 ejection seat the opportunity has been used to provide additional facilities by mounting the oxygen regulator package on the ejection seat in conjunction with the PEC (6). In Tornado the combined oxygen regulator-PEC unit is mounted on the left hand side of the seat pan of the Type 10A seat with the regulator occupying the front and the PEC the rear portion of the unit. This single unit contains those components in the system which have the greatest probability of failure and it can be easily removed and replaced by another serviceable unit in a matter of minutes.

Oxygen Supplies

The main oxygen supply is carried in a stabilised 10 litre liquid oxygen (LOX) converter and delivers gas to the regulator at 70-80 $lb.in^{-2}$ via a quick release self-sealing coupling on the PEC. The LOX converter may be charged in situ or may be easily removed and replaced by a full one for rapid turn round of the aircraft. The emergency oxygen supply is stored in gaseous form at 1800 $lb.in^{-2}$ in a 70 litre cylinder on the rear of the ejection seat and delivers gas at 45 $lb.in^{-2}$ via a reducing valve to the common port with the main supply at the PEC. This arrangement of differential supply pressure ensures that if both the main and emergency supplies are turned on, the main supply will be used in preference. The emergency oxygen supply can be turned on by means of a manual control on the ejection seat pan but is operated automatically on ejection. A pressure gauge indicating the contents of the supply cylinder is mounted near the front of the seat pan where it is easily viewed.

Oxygen Regulator Assembly

The oxygen regulator assembly comprises two demand regulators, one providing airmix and the other 100% oxygen, which share a single inlet port and a single outlet port connected respectively through the PEC to the oxygen supply and the aircrewman's oronasal mask. The main oxygen supply to each ejection seat is controlled by a simple on/off valve placed in the supply line upstream of the PEC and mounted on the side console of the cockpit. The airmix/100% oxygen switch on the upper surface of the regulator assembly operates by diverting the oxygen supply to one regulator or the other so that only one may be in use at a time. The air inlet to the airmix regulator is protected by a valve which opens only when there is an adequate oxygen supply pressure to the regulator. Thus when 100% oxygen is selected the supply pressure to the airmix regulator is removed and the air inlet valve closes. When airmix is selected this feature also provides a

warning to the aircrewman in the event of main supply failure since he would experience difficulty in breathing in.

The airmix regulator is used as the primary regulator whilst the 100% oxygen regulator is normally used only in the event of failure of the primary regulator or when 100% oxygen is required for example due to cabin contamination by toxic fumes. The airmix regulator provides oxygen diluted with air, safety pressure at cabin altitudes above 15,000 feet, pressure breathing above 40,000 ft and incorporates a press-to-test facility. The 100% oxygen regulator provides safety pressure from ground level and pressure breathing above 40,000 ft. The regulators are designed for use with the appropriate National pressure demand oxygen masks (Type P8 (RAF) and MBU 5/P (German and Italian Air Forces)) which are fitted with conventional inlet non-return and compensated outlet valves. The disadvantage with these masks of an excessive rise in the resistance to expiration, for example due to hose pumping on head movement, has been overcome by the use of a regulator dump valve. This valve is fitted between the outlet port of the regulator and the cockpit and uses as a datum the pressure in the reference chamber for the breathing diaphragm of the regulator in use.

Emergency Oxygen Control

By means of a mechanical linkage, operation of the emergency oxygen control automatically selects the 100% oxygen regulator as well as turning on the emergency oxygen supply. If the main supply is intact oxygen will continue to be drawn from it and this will be indicated by the continued operation of the flow indicator ("doll's eye") which senses the main supply line upstream of the entry of the emergency oxygen supply. In addition to the "doll's eye" referring to his own oxygen system each crew member can monitor the other by means of a repeater "doll's eye". If the main supply has failed there will be no interruption to supply which will now be drawn from the emergency cylinder. This will be indicated by a cessation of flow indication by the "doll's eye" and a steady fall in the contents indicated on the emergency oxygen cylinder gauge. If the main oxygen supply is inadequate a low pressure switch in the main supply line will operate the low pressure oxygen caption on the Central Warning Panel. If desired, the primary airmix regulator may be reselected after operating the emergency oxygen control, for example to determine whether it is still performing correctly. However, once operated it is not possible to shut off the emergency oxygen cylinder in flight.

These arrangements permit a simple standard drill for all oxygen system malfunctions namely to check the integrity of connections and operate the emergency oxygen control. If the emergency oxygen supply remains unused the sortie may be continued at altitude.

ESCAPE SYSTEM

The escape system is based on the MBA Type 10A rocket motor assisted ejection seat and provides for safe ejection from zero knots to 625 knots (CAS)/2Mn, from zero feet to 50,000 ft altitude and at aircraft sink rates up to 100 ft/sec. The system incorporates active canopy jettison with sequenced command ejection of both aircrew at the command of either or, by selection, the navigator may initiate and eject only himself.

Cockpit Canopy

The tandem cockpit of Tornado is enclosed by a single "clam shell" opening stretched acrylic transparency whose nominal thickness varies from 9 mm over the rear cockpit to 13 mm over the front cockpit. The profile of the forward part of the canopy is designed to minimise the effects of bird strike. Penetration of this thickness by an ejectee would almost certainly result in severe injury and therefore rapid ejection path clearance is achieved by a propellant canopy jettison system which employs MBA rocket motors on each side at the forward end of the canopy. Canopy jettison is not compromised by the unilateral failure of a rocket motor. Canopy clearance time is most critical for successful ejection under low forward speed/low altitude conditions, more particularly since in sequenced ejection the rear seat is always ejected first. Initiation of ejection therefore also initiates the sequence of canopy unlock and rocket motor firing so that the rear seat leaves the aircraft in less than 0.6 secs and the front seat in 1.0 secs maximum. In the rare event that the canopy unlock/rocket jettison system should fail, the first movement of each seat activates a secondary system which explosively breaks up the transparency over that seat by means of Linear Cutting Cord. Collision or entanglement between front and rear seats is minimised by the use of divergent rocket thrusts applied to each seat.

Canopy jettison or MDC firing alone, ie without ejection, can be initiated from within either cockpit and on the ground MDC firing can be initiated from outside the cockpit. On the ground normal canopy opening or closing can be initiated from either cockpit or from outside. In the case of electrical or hydraulic failure a canopy jack release can be operated from either cockpit which then allows the canopy to be removed manually.

MBA Type 10A Ejection Seat

By comparison with earlier series of MBA seats the Type 10A embodies a number of new features which contribute to enhanced performance and reliability, simplicity of operation and aircrew comfort. In conjunction with the aircrew personal and survival equipment a number of features have also been added to assist the immediate survival of aircrew following a successful ejection. The superficial appearance of the Type 10A seat results directly from the need for rapid and clean parachute deployment at low altitudes and for the maximum protection of aircrew from injury during ejection at high speeds. These changes are associated with a number of less obvious but technical changes, notably the replacement of some mechanically operated systems by cartridge/hot gas operated ones and the introduction of dual systems in which a sequence is immediately resumed if the primary system fails. Thus for example, in the event of a time release failure following ejection, either with or without drogue gun failure, the single operation of the manual separation handle now separates the occupant from the seat and deploys the main parachute. The seat has a single firing handle located on the centre front of the seat pan and, apart from servicing, requires only a single safety pin through the firing handle.

Parachute Head Box. The main parachute and duplex drogue system are contained in the ejection seat head box with the parachute risers running down the face of the box to join the seat mounted simplified combined parachute and restraint harness (SCH). The face of head box is curved to accommodate the aircrew helmet and the box has slab sides for optimum rearward visibility. The main parachute is a GQ/RFD aeroconical parachute provided with water pockets and steering lines. This parachute combines the necessary rapid opening characteristics with sustained deceleration so that the ejectee is not exposed to unacceptably high snatch loads. Recent trials have shown that the addition of water pockets does not compromise parachute performance but terminates the duration of dragging after descent onto water to less than 10 seconds.

Back Rest. The space occupied by the parachute pack in earlier ejection seats has been replaced by a fixed rigid back rest which is overlaid by the soft back pad attached to the SCH. The back rest has been designed for improved comfort using anthropometric data from the 2000 aircrew survey and is contoured with appropriate curvatures in both vertical and horizontal planes to accommodate the profile of the seated back.

Personal Survival Pack (PSP). The sitting platform is formed by a rigid fibre glass PSP which fits into the seat pan bucket. The surface is contoured to complete the sitting profile with the back rest and is overlaid by an energy absorbent comfort cushion. The PSP contains an inflatable life raft and a range of survival aids and incorporates an automatic liferaft inflation device. This device is armed through a static line at man/seat separation and is activated by water immersion. After ejection the PSP may be released on its lowering line by the operation of either one of two quick release fittings at the side of the seat.

Simplified Combined Harness (SCH). The seat mounted combined parachute and seat restraint harness is an improvement and simplification over earlier combined harnesses. Each shoulder strap has only one adjustment buckle and the Quick Release Fitting (QRF) is borne on a fixed length negative G strap which is attached to a lock on the front of the seat pan but is separate from the remainder of the combined harness. The free ends of the seat restraint lap straps bear D rings through which the leg loops pass before looping over the shoulder harness lugs which in turn are then engaged into the QRF. This system thus only employs two instead of four lugs as on earlier combined harnesses. A criticism of earlier harnesses was of only moderate restraint for forward decelerations and of relatively poor restraint for lateral decelerations. These features were due to the point of attachment of the shoulder straps being relatively low down and to a single point in the mid-line. In the Type 10A seat the shoulder harness is attached to either end of a horizontal yoke incorporated in the Power Harness Retraction Unit so that the anchorages each side are 8 inches apart. With the harness go-forward lever unlocked this unit locks if the seat occupant moves forward at a velocity greater than 0.3 metres per second (1 ft.sec^{-1}). On ejection, whether self-initiated or by command and before firing of the primary cartridge in the ejection gun, the Harness Retraction Unit operates and retracts the pilot in not more than 0.2 seconds.

A further simplification of the harness on the Type 10 seat is that no manual parachute rip-cord D ring is necessary as this action is now incorporated in the function of the manual override system.

Leg Restraint System

The leg restraint system is conventional except that, in order to provide optimum leg restraint at high ejection speeds, a double leg garter system is employed. One garter is worn on the thigh just above the knee so that when seated the garter pendant hangs vertically behind the knee. The lower garter is worn below mid-calf level just above the cuff of the flying boot. The leg restraint lines are used uncrossed and are routed from behind through the D ring on the pendant, from inboard to outboard through the D ring on the back of the lower garter and then the taper plug is engaged in its lock on the front cross beam. The taper plug lock is linked to the PEC so that removal of the man portion of the PEC automatically unlocks and ejects the taper plug.

Arm Restraint System

The arm restraint system on the Type 10A seat is operated by movement of the seat on similar principles to the leg restraint line system. The lower end of each line is attached to the aircraft floor through a shear pin and after passing over a 2:1 ratio pulley system is routed up through a snubbing unit on the front cross beam. Above the snubbing unit a further 900 mm (35.4 in) of line terminates in a single female portion manual connector.

The system is used in conjunction with a sleeved lifepreserver which incorporates a length of nylon tape which passes from one wrist up the front of the arm, round the shoulders and across the back, and then down to the opposite wrist. The tape is stitched down at each end and from each shoulder round the back. From the front of the shoulder to the wrist the tape is not stitched but is held in position by an underlying strip of "Velcro". The female connector on each arm restraint line is mated to a male connector normally positioned on the front of the shoulder but which, given sufficient force to break the "Velcro" closure, is free to run down the tape to the wrist. During routine use the connection is made when strapping in to the seat and the line between the connector and the snubbing unit tucked unobtrusively behind the shoulder harness straps and round the sides of the QRF. Any remaining excess is then tucked behind the thigh strap comfort pad so that it can pass to the snubbing unit without interfering with access to the firing handle. Above the QRF the line is retained in position by Velcro tabs, below the QRF it is held back clear of the firing handle by a press-studded loop on the forward face of the PSP.

During ejection, retraction of the lines due to seat movement brings the male connectors down each tape on the lifepreserver sleeves to retract and prevent flailing of the arms. If the hands are in a central position or on the firing handle itself they are brought into or held in this position. If an arm is to one side, as might occur in a commanded ejection, the arm is brought to the side of the seat and held there. In order to prevent the hands being drawn right down onto the snubbing unit a ball is enclosed in the tape, 190 mm (7½ in) from the connector. This ball will not pass through the snubbing unit and 190 mm is the amount of slack required to be able to pass the hand across the right thigh in case it is necessary to operate the Manual Release Handle. Normally however the arm restraint lines are severed by a gas operated guillotine in the snubber unit which operates at man/seat separation. The purpose of the tape passing round the shoulders and back is to provide counter-restraint and it has been shown experimentally that the

reaction during the application of arm restraint does not cause significant head whip. The application of the arm retracting forces occupies approximately 100 msec. Extensive simulation in the laboratory using a range of subjects has demonstrated that apart from occasional mild bruising no physical damage is caused to the subject and that, provided the lower limit of travel of the connector on the sleeve tape is between the radial styloid and the mid-forearm, effective arm retraction and restraint is achieved. Satisfactory restraint has been confirmed on dummies during ejections up to 625 kts in the ejection seat test firing programme.

PSP Lanyard Sticker Clip. The connection between the PSP/liferaft lowering line and the PSP lanyard on the aircrew lifepreserver is not made directly but through an arrowhead connector which engages into a sticker clip on the left side of the seat pan. Thus at man/seat separation the arrowhead holds in the sticker clip until the separation force exceeds 40-60 lbs.ft when it separates from the clip. This initial holding action puts tension on the lifepreserver PSP lanyard and extends a tuck in the lanyard. A cord is attached between this tuck and the Personal Locator Beacon (PLB) and when pulled the cord automatically initiates PLB transmission.

Personal Equipment Connector (PEC)

All personal services to the man (low or medium pressure oxygen supply, anti-G suit inflation, helmet ventilation and R/T connection) are made through the PEC. The PEC comprises three portions namely aircraft, seat and man portions with the seat portion mounted on the left side of the seat pan and the detachable aircraft and man portions connected respectively to its lower and upper faces. All services except emergency and low pressure oxygen are supplied to the seat portion through the aircraft portion, the emergency oxygen supply is connected directly into the seat portion and low pressure oxygen is supplied to the seat portion from the oxygen regulator. The necessary outlet supplies are determined by the choice of PEC man portion. Thus in the standard man portion the high pressure oxygen and helmet ventilation ports remain blanked off and in the NBC version the high pressure oxygen and helmet ventilation ports are opened and the low pressure oxygen port blanked off. National differences, for example of anti-G suit hose connections, are accommodated downstream on the ends of hoses etc and thus do not affect design of the PEC man portion sole plate.

When the ejection seat is mounted in the aircraft, the aircraft portion is latched on to the seat portion to make connection with the various services. The handle of the aircraft portion is attached to the floor of the cockpit by a static line which disconnects it from the seat portion as the seat moves upwards during ejection. The man portion is similarly latched on or unlocked manually by the aircrew member as he boards or leaves the aircraft, however the locking latch for the man portion subserves two important functions. Firstly, during routine use operation of this latch releases the locks on the leg restraint line taper plugs. Secondly, at man/seat separation during ejection the latch automatically unlocks and releases the man portion of the PEC. In order to protect the integrity of vital supplies following ejection various self-sealing valves are provided in the PEC. When an ejection seat is unoccupied the PEC man portion is replaced by a blank sole plate which acts as a self sealing dust cover.

STRAPPING-IN AND EGRESS DRILLS

The strapping-in and egress drills for Tornado are straightforward. The order in which actions are carried out is designed to minimise the possibility of incorrect routing of hoses, lanyards etc when strapping-in and for a clean separation when vacating the seat and cockpit. Although the method of choice for a serious emergency on the ground would be ejection there will be occasions when ejection is not possible. One advantage of the routine egress drill is that the identical drill is used in an emergency ground egress so that aircrew are in constant practice and do not have to memorise a special emergency drill.

Aircrew will normally go to the aircraft wearing leg restraint garters and with PEC attached to their personal hoses etc. The essentials of the strapping drill are as follows:

1. Remove dust cover and connect PEC to seat portion.
2. Route leg restraint lines and engage taper plugs.
3. Strap into SCH routing personal supply hoses from PEC underneath the left harness lap strap.
4. Connect and stow arm restraint lines.
5. Connect PSP lanyard to sticker clip arrowhead routing the lanyard outside the harness lap strap and PEC supply hoses.

The logic of this drill is simple, for example if the leg restraint lines are engaged before the PEC is connected the taper plugs will be unlocked and released when subsequent engagement of the PEC depresses its locking latch. Similarly if the PSP lanyard is connected first it will almost invariably be routed underneath the lap strap and hoses.

The egress drill is equally simple and consists of four actions:

1. Disconnect arm restraint lines.
2. Disconnect PSP lanyard.
3. Disconnect PEC.
4. Operate harness QRF.

Again the logic is simple. If the harness is released before the arm restraint lines or the PSP lanyard they tend to be overlaid by the harness and are more difficult to locate and release, especially in the dark. No special action is required for the leg restraint lines which are released by disconnection of the PEC.

A total of over a thousand simulated emergency egresses have been carried out during the 100 aircrew trial and from an actual aircraft cockpit. Mean egress time to vacate either cockpit was 10-13 seconds although it can be done in as little as 8 seconds. Because of the angle of the canopy at the rear cockpit,

egress from this cockpit takes about one second longer than from the front cockpit. Similarly wearing bulky winter clothing assemblies adds about one second compared with lightweight summer assemblies.

By comparison with similar egress trials on other aircraft these times compare as well or even better despite the additional actions introduced by the arm restraint system. Initially it had been suggested that the need to locate and disconnect the arm restraint connectors would cause inordinate delays in a rapid egress. However, from an analysis of 48 egresses in which split times were taken the mean time to disconnect both arm connecters was only 3.1 seconds.

All but approximately 3% of egresses were 'clean' and without interruption. The only occasions on which rapid egress was effectively prevented was due to entanglement of the leg restraint lines due to incorrect routing. Included in the 3% were occasions in which release was hesitant due to a temporary snag which then cleared, usually by momentarily easing the tension on the offending parts. Thus provided the strapping-in procedures are done correctly it is considered that the probability of a serious entanglement is remote but that in a situation where straps and connectors etc are flying about aircrew should be aware that random and unpredictable entanglements may occur.

AIRCREW EQUIPMENT ASSEMBLIES (AEA)

The agreed tri-National policy is that the personal equipment in Tornado should be National fit. In practice all three Nations have relied upon the use of their standard items of AEA and have introduced special items only where they are essential.

Protective Helmet and Oxygen Mask

The special feature of the protective helmet and oxygen mask is that they should be suitable for ejection at speeds up to 625 kts. This requires adequate helmet strength to withstand impact against the parachute head box and a sufficiently robust oxygen mask and helmet/mask suspension system. Initially it was considered that an automatic visor lowering system would be required, however during development of the Mk 4 helmet it was demonstrated that this was not essential to ensure retention of the helmet and mask provided a close fitting visor was used and the helmet chin strap and mask suspension system were reliable. The UK intend therefore to use the P8 oxygen mask (which has an improved "bicycle chain" harness) with the Mk 3c and later the Mk 4 protective helmets. Both helmets incorporate a manually operated lowering system with two polycarbonate visors, a close fitting inner clear visor and an outer tinted visor. The primary purpose of the clear visor is for protection against the effects of bird strike and it will be lowered when there is also a risk of high speed ejection.

Lifepreserver

Apart from the addition of sleeves as an integral part of the arm restraint system, the lifepreservers are required to provide automatic inflation upon water entry, to be compatible with the system for automatic activation of the PLB and to be "blast proof" ie withstand ejection at 625 kts. They must of course still also meet the conventional standards for buoyancy, flotation angle, self righting properties etc and make provision for the carriage of some survival aids. In addition they provide a method of securing the upper end of the PEC oxygen hose.

The UK lifepreserver will be the BASE Mk 18 while the German and Italian Air Forces will use the Secumar 10HLA. Both are available in two sizes based on chest girth so that aircrew with a chest girth in excess of approximately 1070 mm, 42 in (95th percentile) require the larger size. At present each size has one standard sleeve length. Although they differ in detail, for example the Mk 18 employs only a single inflation stole whereas the Secumar 10HLA has two, only one of which inflates automatically, the principle of a blast proof stole which opens automatically is achieved along similar lines. The inflation stole(s) is contained in a horseshoe pouch around the neck which is closed by a zip fastener. On the Mk 18 lifepreserver this zip is interrupted at the back of the neck and the ends held together by keepers. When the stole begins to inflate within the pouch the keepers are forced off and the zip splits open to release the stole from within the pouch. On the Secumar 10HLA a special clip on the zip near the extremity of the right lobe of the stole performs the same function. This system has been shown during ejection tests to be reliably blast proof and provided an adequate gas inflation charge is used, to open automatically upon inflation of the stole. Both lifepreservers employ mechanical auto-inflation systems based on the dissolution of a soluble plug or pill on entry into water. The gas inflation systems of both lifepreservers may also be operated manually by means of a blast proof firing handle. At present both lifepreservers are produced with a single sleeve length for each size. However experience during the 100 aircrew trial showed that although the criteria for achieving arm restraint could be met the quality of fit was not always satisfactory. This is not unexpected since one sleeve length is being made to accommodate the full range of arm lengths. Thus when a relatively long arm is accommodated in this sleeve upward reach may be limited and there may be separation between the cuff of the sleeve and the cuff of the flying glove. It has been recommended therefore that production lifepreservers should have three alternative sleeve lengths. By selecting the intermediate length sleeve so that it caters for the majority around the peak of the distribution curve for arm length, it should be possible to retain a common "popular" size with a minimum requirement for the two extremes. The sleeves and backs of both patterns of lifepreserver are manufactured in an open mesh material in order to minimise the heat load imposed by the garments. In both, the personal locator beacon is located in a pocket on the left side of the waistcoat, the pocket is adjacent to the PSP lanyard in order to allow connection with the auto-arming cord attached to the tuck on the lanyard. From the PLB situated in its pocket a connecting cable leads to the aerial assembly which is pre-sited and stowed within the lifepreserver stole cover. The aerial erects automatically upon inflation of the lifepreserver stole. The Mk 18 lifepreserver uses the PYE PLB and auto-aerial assembly, the Secumar uses the BECKER Emergency Transceiver MR 506 and SWA 2 antenna. Both patterns of lifepreserver thus provide both automatic activation of PLB transmission following man/seat separation after ejection and automatic inflation of the lifepreserver stole upon water entry.

Aircrew Coveralls

Because the use of double leg restraint garters tends to limit the full use of pockets provided on the legs of various external garments, the UK range of garments incorporates garter tunnels which run beneath the thigh and lower leg pockets. The location and width of these tunnels is critical both for ease of use and for the achievement of proper leg restraint and is complicated by the fact that the aircrew population must be accommodated in ranges of clothing with a limited number of sizes. The Mk 2 external anti-G suit is provided in small, medium, large and extra large sizes and while there are girth adjustments the leg lengths are fixed for each size. The Mk 10 immersion coverall and the Mk 15 flying coverall (under development for Tornado and manufactured in flame retardant Nomex material) are available in 9 sizes and the two piece Cold Weather Flying Suit Mark 3 in 8 sizes. It was established during the 100 aircrew trial that with tunnels approximately twice the width of the garter the criteria for both correct positioning and ease of use can be met satisfactorily on all garments. Apart from the provision of garter tunnels the immersion coveralls, which are manufactured from a ventile material, incorporate a fabric collar which covers the rubber neck seal. This has been found necessary to prevent tearing of the neck seal during test ejections at high speeds.

CONCLUSIONS

The all round performance of Tornado placed a number of new demands upon the aircrew systems and personal equipment for the aircraft. In particular there was a danger that the efforts to meet the requirements for safe escape by ejection at the extremes of speed and altitude and for the post-ejection aids to survival could result in such complexity and encumbrance that the ability to carry out routine tasks, comfort etc would be compromised. From the outset continuous assessment, either in the field or using a representative cockpit mock-up and ejection seat in the laboratory, has kept pace with design and development and thus avoided the creation and perpetuation of unrecognised interactions and incompatibilities. In particular the trial involving 100 aircrew has demonstrated the acceptability and compatibility of definitive items and systems. Thus while the final judgement must await introduction of the aircraft into Squadron service it is considered that the aircrew systems and personal equipment represent a significant advance over previous systems with little or no cost to aircrew comfort and convenience. Indeed this opinion has been confirmed by flight test experience to date.

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INFORMATION TRANSFER FOR IMPROVED PILOT PERFORMANCE

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ABSTRACT

When compared to fighter aircraft used in past conflicts, today's fighter, as typified by the F-16, represents a greatly enhanced level of performance as a counter air weapon system. The increase in performance has been accompanied by a corresponding increase in pilot workload. System development must stress the pilot requirements during the conceptual and design phase. Several features of the F-16 missile fire control modes do in fact reflect this requirement. In addition, however, the questions of what kind, how much, and in what format information should be made available to the pilot must be answered.

The Air Force Avionics Laboratory, Reconnaissance and Weapon Delivery Division's MISVAL (Missile Launch Envelope) Program was established to address the missile fire control issues associated with the new generation of fighter aircraft and tactical air-to-air missiles. During the MISVAL Program, a new missile launch envelope (MLE) display concept (pilot cue), the Missile Intercept Confidence Factor (MICF), was developed by Dr. Charles C. Scott of General Dynamics/Fort Worth Division. The MICF concept greatly enhances the pilot's missile launch performance, particularly against a maneuvering target. The MICF provides the pilot his position relative to the MLE maximum, no-escape, and minimum launch ranges. The MICF, its development process, and the potential impact on aircrew performance and training are the subjects of this paper.

BACKGROUND

Since the South East Asia Conflict, the development of new aircraft, new sensors, and new on-board processing capabilities have greatly enhanced tactical fighter aircraft systems. The F-16, F-15 and F-14 represent a new, greatly enhanced level of maneuverability in air-to-air combat. The transition to digital processing in the central and radar computers of these systems have greatly enhanced their capability of target detection and target track. The enhanced data processing systems have provided an in-flight information generating system never before possible. Finally, the continued development of the Sidewinder (AIM-9), Sparrow (AIM-7), and Phoenix (AIM-54) missile systems have greatly enhanced the lethality of tactical aircraft as counter air weapon systems. The recently concluded AIMVAL/ACEVAL Study dramatized the lethality of the current and projected air-to-air arena.

The increase in computation capability provided by on-board digital computers has led to a corresponding increase in the information available to the fighter pilot. In many instances the amount of information exceeds the pilot's ability to observe and assimilate it. This is particularly true in the air combat maneuvering (ACM) environment. In missile fire control, the relationship of display requirements to a missile launch envelope algorithm is both extremely complex and critical. It is complex due to the widely varying ranges and tactical scenarios in which air-to-air missiles are the primary, or only, weapon available; and it is critical due to the large number of factors that combine to form the actual MLE for a particular missile, fighter, target, and engagement geometry.

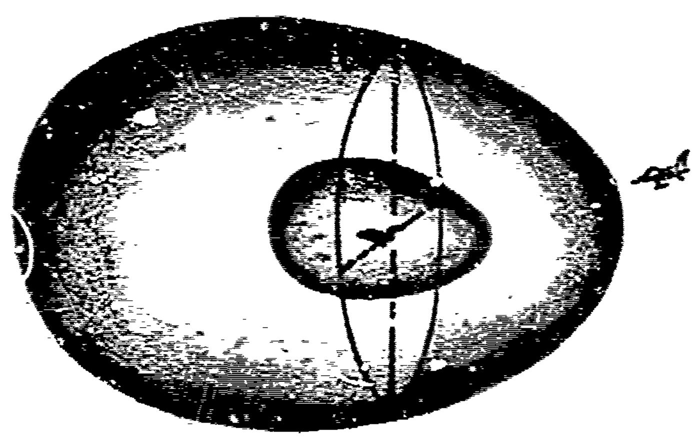

Figure 1 Target Centered Three-Dimensional Missile Launch Envelope with an R_{MIN} and R_{MAX} Boundary

The MICF Concept, by better describing the air-to-air engagement dynamics, provides the pilot improved information content at a lower information rate. Prior to describing the MICF and discussing its development process and potential impact on aircrew performance and training, however, a brief description of missile launch envelope terminology and of the pilot role in missile fire control is provided. In addition to establishing the context in which the MICF display concept was developed, the descriptions should provide more insight into the complexity of the missile fire control decision the pilot is confronted with.

Missile Launch Envelope Terminology - While attempting to deliver an air-to-air missile in combat, the pilot is confronted with the decision of when to launch the missile. From a systems viewpoint, the pilot is aware that in a three-dimensional space there are only particular volumes of space from which a successful launch can be made. This volume is depicted in Figure 1 and is defined as the missile launch envelope (MLE). The target aircraft is located in space at time equal to zero (i.e., launch time) and any launch from within the volume between the inner and outer shaded surfaces will result in a successful missile intercept.

A more typical and more easily understood presentation of the MLE is depicted in Figure 2. This presentation is obtained by taking a slice (in the plane of the engagement) through the volume of Figure 1. It is quickly noted that there are two boundaries depicted. The outer boundary consists of all maximum range (R_{MAX}) points, i.e., launches at points along the line-of-sight between the attacker and target which are outside these points will result in a lost missile. Conversely, the inner boundary consists of all minimum range (R_{MIN}) points, i.e., launches at points along the line-of-sight between the attacker and target which are inside these points will result in a lost missile. The pilot's launch decision appears to depend on his being able to achieve a condition in which his current range (R) is between R_{MIN} and R_{MAX}. Both R_{MIN} and R_{MAX} boundaries, however, vary as a function of several different parameters, i.e., the MLE boundaries depend on a n-dimensional space of parameters. The effect that the n-parameters have on the MLE boundary (hence the pilot decision, $R_{MIN} < R < R_{MAX}$) varies considerably depending on the parameter and boundary of interest. A critical parameter in determining the boundary shape is that of target maneuver. The MLE depicted in Figure 2 is for a non-maneuvering target. Figure 3 depicts the MLE for the same target

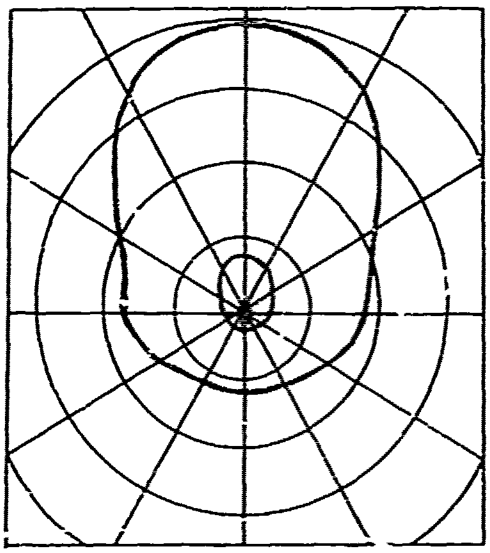

Figure 2 Non-Maneuvering Target Missile Launch Envelope

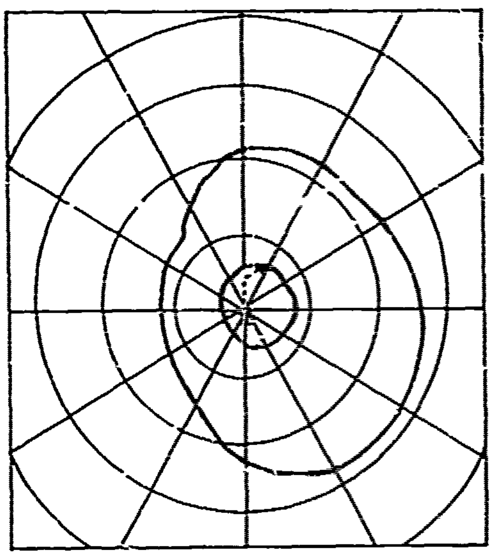

Figure 3 Maneuvering Target Missile Launch Envelope

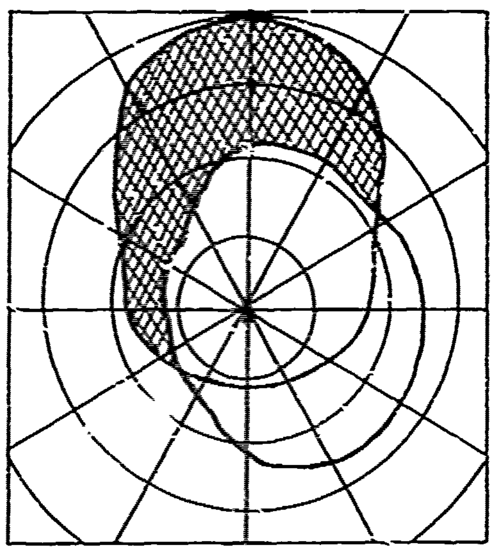

Figure 4 The Target Controls the Missile Launch Envelope by Maneuvering

applying constant load factor during the time-of-flight of the missile; and Figure 4 is an overlay of the two MLE's. If the pilot had launched a missile at the non-maneuvering target of Figure 2, the cross-hatched area of Figure 4 represents that area in which an unsuccessful intercept would have occurred if the target maneuvered as in Figure 3. Further discussion of MLE's will be deferred until the description of the MICF.

The Pilot Role in Missile Fire Control - The common denominator to all missile fire control engagements is the requirement for the pilot to decide when, or if, to launch. The previous section on MLE's described the information required for this decision. This section will briefly discuss certain key aircraft systems which prepare and support the pilot decision for missile launch. A majority of the description will describe F-16 systems. Where other systems are discussed it will be specifically noted.

The F-16 control/display interface was designed for "hands on throttle and stick" operation, permitting the pilot to carry out the majority of tactical operations in a head-up environment. The interface allows the pilot options based upon the dynamics of his particular mission. The pilot can interface with the fire control system through the radar, fire control nav, Heads Up Display and stores control panels and the Horizontal Situation Indicator and other instruments. As indicated, however, switches on the side stick controller and the throttle provide for critical "air combat interfaces". Two of the three F-16 air-to-air missile modes, the missile override and dogfight modes, are selected through a throttle switch. Both the positioning and functioning of the missile and dogfight mode switches reduce pilot workload in the ACM engagement. A critical function provided by selecting either of these two modes is that of automatic target acquisition. This precludes the pilot from having to go heads down in the cockpit in

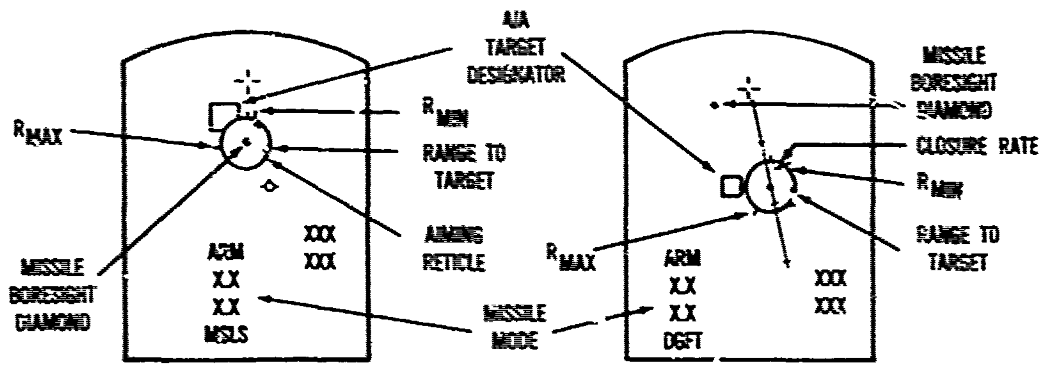

Figure 5 F-16 Type Missile Launch Displays

order to slew the radar cursor and manually acquire the target. All three missile modes, however, provide essentially the same information with which the pilot makes his launch decision. Figure 5 depicts F-16 type symbology associated with the missile/missile override modes and the dog-fight mode respectively. For comparison, F-15 type symbology for the short range missile mode is depicted in Figure 6. In addition to providing the pilot R_{MIN}, R_{MAX}, and current range, the F-16 flashes the reticle when in zone and the F-15 provides an in-range and shoot cue. Both a heads up display and a head down display are provided to the pilot. The pilot is being provided the instantaneous launch solution. The dynamics of the conditions are depicted by the relative motion of the R_{MIN}, R_{MAX}, and current range symbols. The pilot must assess the relative "goodness" of the conditions depicted by this launch symbology and then make a launch decision.

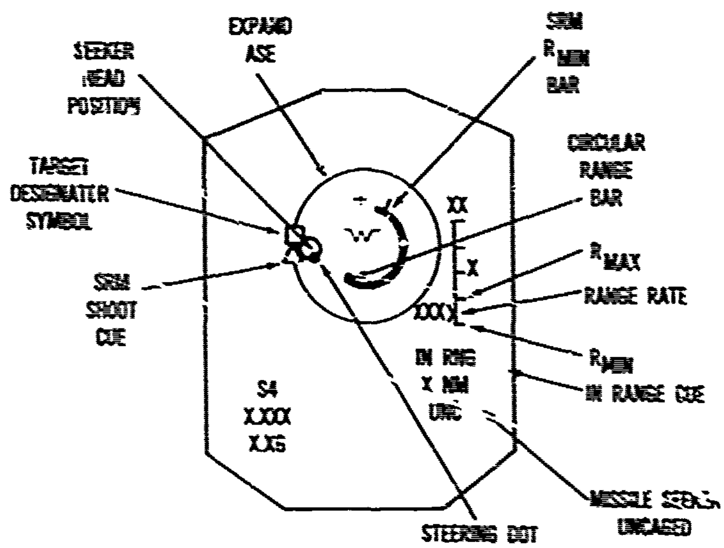

Figure 6 F-15 Type Missile Launch Display

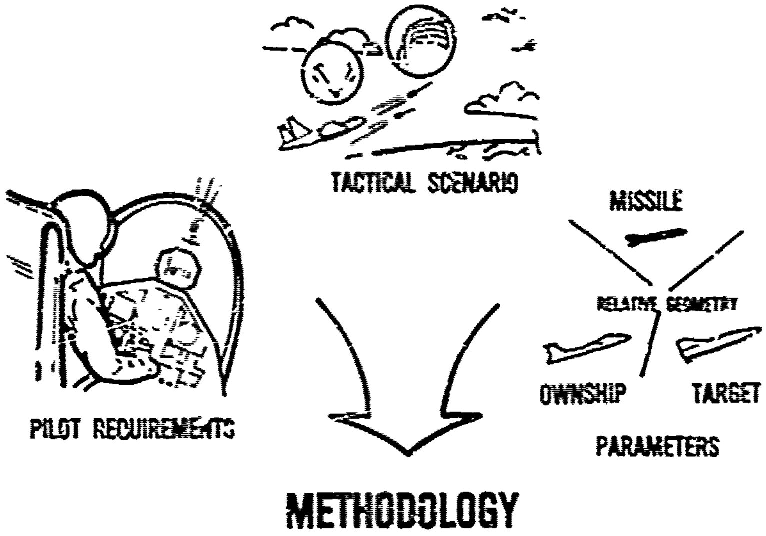

Figure 7 Human Factor Issues Included During Algorithm and Display Design Process

MISSILE INTERCEPT CONFIDENCE FACTOR (MICF)

Figure 7 depicts the approach taken by the MISVAL Program in the development of missile fire control mechanizations and displays. The important thing to note is that the man's interface with the other factors is considered during the initial algorithm and display design. The questions of what kind, how much, and in what format information should be provided to the pilot is an integral part of the design process. While they are important real world constraints, the ability to compute and physically transmit or display the information should not initially dictate the information requirements of the pilot. As noted in previous sections, a considerable amount of missile fire control information is available in the F-16, and more efficient means of calling-up or displaying this information are also available. The questions of what kind, how much, and in what format the information should be provided still remains. Dr. Scott, in a paper on the MICF Concept, identified four characteristics which a display for air-to-air missile weapon delivery should possess:

(1) Highly Visible

(2) Easily Interpretable

(3) Low Pilot Workload

(4) Engagement Trend Indicator

The latter of these four characteristics is a critical element in the whole of flying. A very simple example is a pilot's instrument "cross check". The pilot is not only interested in the instantaneous values of the various flight instruments, but also in the rate of change of their values. The lack of an adequate engagement trend indicator in current missile fire control systems displays was identified during the MISVAL design process. In terms of current MLE displays, the relative motion of the R_{MIN}, R_{MAX}, and R tics and other shoot cues do not provide the pilot with adequate information on the dynamics of the engagement. The MICF evolved from the identification of this information requirement.

The MICF is based on the use of a no-escape missile launch range (R_{NE}). The no-escape MLE is defined as the smallest possible value that the maximum launch boundary can have for a target maneuver during the flight of the missile. The MICF is defined as follows:

$$
\text{MICF} = \begin{cases} \dfrac{R_{MAX} - R}{R_{MAX} - R_{NE}} & R_{NE} < R < R_{MAX} \\ 1 & R_{MIN} < R < R_{NE} \\ 0 & R > R_{MAX} \text{ or } R < R_{MIN} \end{cases}
$$

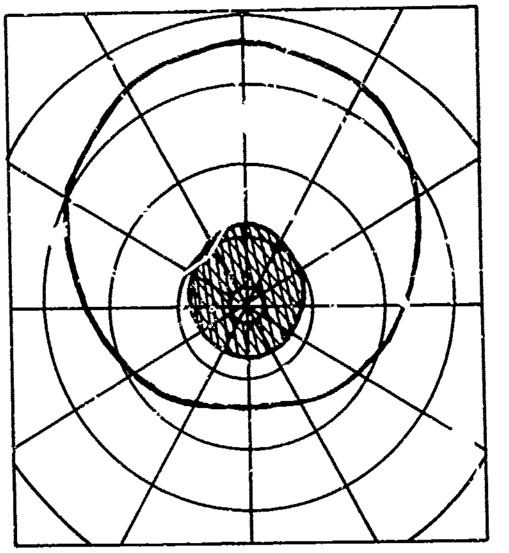

Figure 8 The No-Escape Region of the Missile Launch Envelope

Figure 8 depicts the relationship of the no-escape boundary to the R_{MAX} and R_{MIN} boundaries. The MICF relates the pilot position to these three boundaries. The cross hatched area, the area between R_{MIN} and R_{NE}, in Figure 8 is that area from which the target cannot defeat the missile. In this area the MICF would be one; or if placed in terms of percentage - 100%. The MICF (in percent) decreases linearly, along the line-of-sight, from the 100% at the no-escape boundary to zero percent at the maximum range boundary. Outside the maximum range boundary the MICF is equal to zero. This is illustrated in Figure 9. Note that an F `¿ type display has been used as an example format for displaying the MICF value. The percentage of the aiming reticle which is darkened (illuminated) is directly proportional to the percentage of MICF. For an airborne s, .., the no-escape maneuver would have to be approximated. Currently, the MICF does ot account for several factors which are critical to a successful missile intercept. The extent to which other factors can or should be included as part of the MICF is a subject for further study As described, herein, the MICF is based on kinematics only. Even with this constraint, however, the pilot is provided information which allows him to assess both the relative goodness of his current launch conditions and the corresponding improvement or worsening of those conditions. Information about the dynamics of the engagement, as controlled by both pre- and post-launch target aircraft maneuver, is now available.

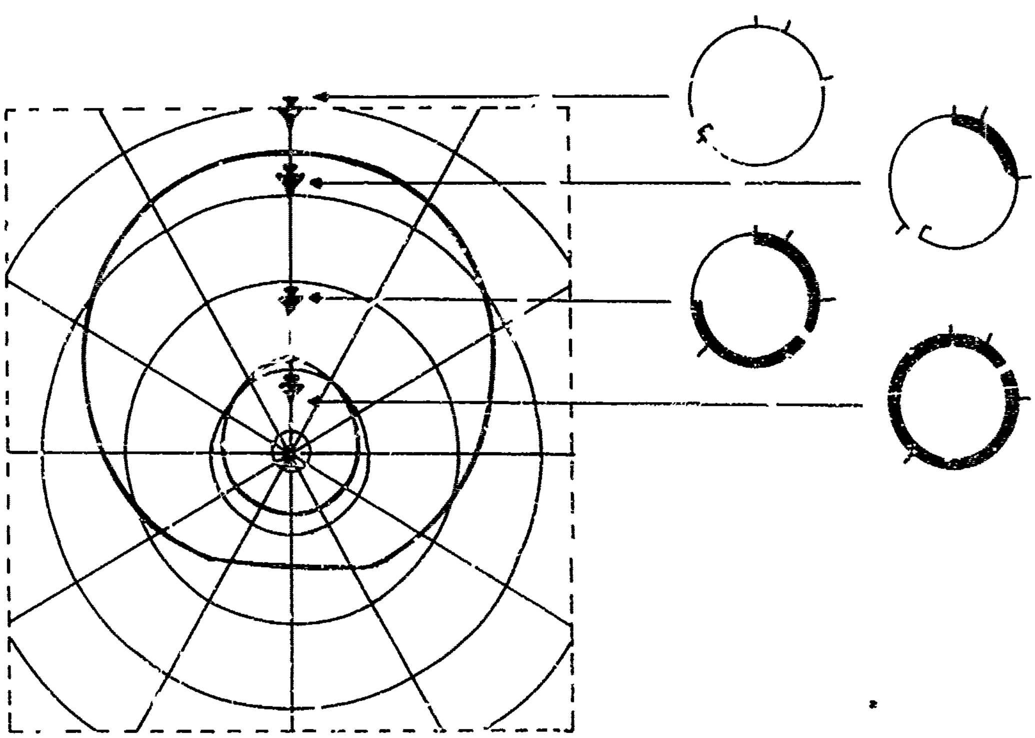

Figure 9 Correlation of the MICF Cue with Fighter Penetration into the Missile Launch Envelope

PILOT CONSIDERATIONS

The :gh levels of training and experience required by fighter pilots is largely the resu' of the unpredictability associated with any particular tactical engagement. The pilo' ust be able to react to new and very rapidly occuring tactics and maneuvers. The MICF as a relative positi-- and trend indicator is particularly suited to this environment. It allows for raction of the pilot with the fire control system solution. As Dr. Scott desc « it, "the pilot utilizes MICF as a shoot cue, but one

that contains shades of gray rather than being black or white". A pilot may choose to launch with a low MICF, or he may decide to maximize his MICF prior to launch. The pilot's experience and judgment will determine the decision he makes. The decision is enhanced, however, by a pre-launch assessment of the target's likelihood of evading the missile.

While the MICF is still at a conceptual stage and remains to be fully explored and exploited, several intuitive insights as to the MICF's usefulness to pilots can be made. The MICF will provide an easily interpretable launch cue that will reduce overall pilot workload. As noted previously, the MICF contains information about R, R_{MIN}, R_{MAX} and R_{NE}. During an engagement, each of these items of information is dynamic. If the engagement is dynamic, either visual or non-visual, the bit rate of information which the pilot must absorb and interpret is very high or excessive. This accounts for several pilots' desire for a "simple" shoot light. The MICF presents the pilot with one item of information which can be displayed as a linearly decreasing/increasing function. The bit rate of information is reduced and its interpretability increased. It has been demonstrated that a human has a maximum absorbable bit rate of approximately 50 bits/sec, and that a transfer of this usable bit rate is possible between visual tasks. Intuitively, the MICF provides the pilot more informational content at a lower bit rate. The lower bit rate required for the missile fire control launch decision allows the pilot to perform the other tasks at a higher level of efficiency.

In addition to being difficult to interpret in dynamic engagements, the values and rate of change of R, R_{MIN}, R_{MAX}, and R_{NE} will vary for each specific engagement. In other words, the display information the pilot saw in the low altitude, high-speed, nose-on-attack yesterday will bear little resemblance to the medium-altitude, beam-attack display he has today. The variation in this information, stimulus, for the pilot launch decision again accounts for the frequent request for a shoot light. Further, it is reflected in the wide variation of observed pilot use of the information available for missile launch in current systems. The implications for pilot training are obvious. In contrast, the MICF provides a single-valued function which could be correlated with each missile launch success or failure. The pilot can, through training, determine his assessment of what a 50% or 75% MICF means tactically. Note that the MICF incorporates all the information currently provided to the pilot and has the ability to function as a shoot light. As illustrated in Figure 8, if it is desired for the more experienced pilot, the individual information items could be displayed concurrently with the MICF.

Again, it should be noted that the MICF concept is at a conceptual stage and that the inferences made above have not resulted from experimentation or test. Further development of the MICF is on-going.

SUMMARY

As the system demands on a single-seat fighter pilot increase, increased emphasis must be placed on what kind, how much, and in what format information should be provided to the pilot - the MICF is an example of this emphasis. The MICF concept has been developed to provide the pilot information about the engagement dynamics of an air-to-air missile engagement. It attempts to account for the critical parameter, target maneuver, by bounding the possible aerodynamic boundaries by calculating upper and lower boundary limits. A no-escape target maneuver is utilized to establish the lower boundary and the current maneuver is used for the upper boundary. The MICF factor relates the pilot's position relative to these two boundaries and a minimum range boundary. As an interceptor varies its position within the MLE boundaries, the MICF varies between a value of zero to one and presents the pilot an indication of the increasing/decreasing goodness of his launch condition. The MICF allows the pilot to be interactive with the fire control system. Through an assessment of the tactical situation the pilot can determine whether to accept a low confidence launch or to maneuver to a more favorable launch position.

A decrease in the information bit rate required for the missile fire control task is expected to result from the MICF Concept. This will result in a corresponding improvement in other task areas. Finally, the MICF Concept will provide a launch cue which will allow for improved pilot training, understanding, and performance.

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Human Factors Aspects in High Speed Low Level Flight

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Introduction

To quote from the theme for Session A:- "Any weapons system is no more effective than its human operators: in that sense the system is merely an extension of the operator's sensory, muscular and cognitive capabilities in responding to mission and environmental stress. To ensure accomplishment of operational missions, the relationship between man and machine must be complementary and compatible."

In order to achieve a satisfactory relationship much thought and effort is required on this aspect by designers and aircrew, with particular emphasis on a feed-back of experience from the operational environment. Conclusions reached from past experience are that no matter how much time and effort is spent by cockpit committees using detailed mock-ups, simulators and combat studies we still find shortfalls when we finally reach the operational environment with a new combat aircraft. The state of the art is such that these shortfalls are becoming less numerous and hopefully, less critical.

Another aspect is the operational requirement which calls for a very high degree of system capability, which on the day the specification was written was obviously considered to be the requirement for the timescale being considered, but on reaching operational service is sometimes found to be redundant or at least not cost effective, hence the necessity for involvement of operational aircrew in the design concept stage of a new combat aircraft.

Although this paper was requested for Human Factors in relation to the Tornado, the aspects I will cover relate to any aircraft whose primary operational zone is high speed, low level.

Crew Comfort

Crew comfort must come high on the list of priorities. The adaptability of the human species is well known and aircrew will adapt and accept a high degree of discomfort in order to achieve mission success, however, there is a direct relationship between comfort and operational efficiency. I will briefly discuss crew comfort under the following headings:-

- Flying clothing
- Combined harness, arm, leg and head restraint
- Helmets
- Anti 'g' protection
- Ejector seat
- Cockpit conditioning
- Cockpit layout
- Noise aspects
- Ride comfort.

Flying Clothing

We hear much talk from aircrew on "shirt-sleeve" environment, but do we really mean "shirt-sleeve". If we consider what can happen in a war situation, faced with the possibility of battle damage, ejection, survival, escape and evasion, then we must cater for these possibilities but also endeavour to avoid making the aircrew feel like trussed chickens. Account must also be taken of the requirements for long periods on standby fully dressed, extended flight on Combat Air Patrol and oversea operations, particularly in winter in the European theatre and not forgetting long-range ferry flights which can extend over extremes of environmental conditions.

Overwater operation requires the provision of a lifepreserver which must not impede the movement of head and arms or the vision of cockpit controls and panels and of course in European winter conditions an anti-exposure suit is also required.

To sum up, not an easy task for the flying clothing specialists.

Combined Harness, Arm, Leg and Head Restraint

Unless an escape capsule is utilised, then an ejector seat facility such as fitted in Tornado and designed to provide safe/survivable high speed, low level escape up to 600 kts. plus is required. This in turn requires a simple and comfortable combined harness and with the necessary arm, leg and head restraint to prevent flailing. Normal strapping in, scramble and emergency ground egress requirements also have to be considered. How these requirements are met in the Tornado will be covered by another speaker.

Helmets

There is a very large range of helmets available all with their good and poor features. However, the main requirements are that they must be comfortable, afford a high degree of protection against impact, have good sound exclusion properties and be light in weight. Visor protection against bird strikes is essential in the low level role. The degree of visor shading is important and must enable the head down instruments and cockpit displays and controls to be seen and at the same time afford sun glare protection. The current vogue is to have two visors, one clear and one shaded. Helmet colour has been the subject of crew room discussion since the camouflaged has succeeded the white painted helmet. The two main points raised are the apparent heat reflection advantage of the white helmet in hot sunny climates and its disadvantage in acting as a prominent aiming point for an attacking gun armed fighter pilot.

Anti 'g' Protection

Although the tilting of seats is becoming more fashionable as a 'g' threshold raiser the anti 'g' suit is still with us. During high speed low level terrain following development flying attention was focussed on the anti 'g' system scheduling. The conclusion of the aircrew was that the rapid onset of anti 'g' pressure required for air to air combat was undesireable for terrain following due to the frequency and severity of the thump in the stomach. Action is now in hand to alter the schedule for Tornado.

Ejector Seat

Crew posture and comfort is dependant on the sitting position in the seat, and comfort coupled with the ability to operate cockpit controls without stretching is considered to have a good psychologial effect. Comfort is again stressed as of major importance. Minor discomforts can reach major proportions after sitting for many hours on standby or on extended flights such as Combat Air Patrol or a long range ferry flight.

Cockpit Conditioning

Another prime factor in crew comfort. The designers task in providing pressurisation, air flow, air distribution and temperature controlability to meet all operating conditions, on the ground, in flight, and in world-wide environments is formidable. This is a design area where ground rigs are useful but invariably shortcomings become evident when assessing the system in the actual aircraft under operational conditions. An inefficient cockpit conditioning system can seriously affect the crews' performance and therefore mission success.

Cockpit Layout

Although cockpit layout and control accessibility have been discussed in depth at previous AGARD meetings the importance of good layout of indicators and controls cannot be over-stressed. However, I do not intend to discuss these aspects any further in this paper.

Noise Aspects

Cockpit noise can and does eminate from various sources such as cabin conditioning, demisting system, aerodynamic noise caused by poorly fitting canopy or airframe panels and can be attenuated to some degree by a well fitted helmet with good sound exclusion properties. However, this does not absolve the aircraft designers from the responsibility to reduce the overall cockpit noise to an acceptable level. By this we mean that the crew should be able to communicate through the intercom. system up to the design Indicated Air Speed (I.A.S.) of the aircraft. Unfortunately this is not so with the majority of current multi-seat combat aircraft capable of high I.A.S. and is psychologically bad for the crew who know they cannot communicate by voice when in a situation that requires them to use the max. operational speed capability of their aircraft. Fortunately for us, the Tornado is unique in that normal intercom. is useable up to the design speed, we also like to think that this is the result of good design and attention to detail and not just good luck.

Ride Comfort

Ride comfort is obviously another prime factor in the high speed, low level role and merits a paper on its own. Crew tolerance levels V's time is an important parameter and can be decisive in the mission success context. How ride comfort is achieved will be dealt with by another speaker during the course of this meeting.

Physiological Aspects

Surfice to say that high speed, low level flight is usually bumpy, hot, noisy, requires a high degree of concentration and produces a high workload. It can be considered one of the most taxing operational tasks but at the same time, most stimulating. The crew's sensitiveness to stimuli (tactile, visual and aural) has to be considered in this working environment along with re-action time, resistance to fatigue (tolerance levels V's time) and adaptability. If the crew comfort aspects already mentioned receive satisfactory design attention then the undesireable physiological effects will be reduced to an acceptable level.

Workload and Worksharing

Cockpit design is of prime importance when considering workload and worksharing and is affected by such factors as scenario, equipment and operational requirements. This is a complex study on its own and has been dealt with at previous AGARD meetings and will also be discussed later in this meeting.

However, worthy of further study in this area is the complexity of modern multi-role weapons systems and the ability of the crew to utilise the full system capability and to cope with the many possible redundancies. This aspect will of course have an significant impact on crew training.

A continuous state of crew training is required if a high degree of operationsl effectiveness is to be maintained - this poses problems with regard to flight hours available, availability of suitable low level training areas and weapons ranges day and night. The high cost of flying is also a significant factor and hence operationally realistic flight simulators will, and are, playing an important role in this area.

Psychological Aspects

The mentally trying task of a crew being flown by an autopilot at high speed, low level, at night in poor weather conditions is somewhat daunting, and obviously requires a very high degree of confidence in the safety integrity and reliability of the safety critical systems. It only requires a system 'hiccup' under these conditions to reduce the crews confidence level to zero. It is considered that this is an area where the flight simulator can psychologically prepare a crew for system malfunctions in complete safety, and thereby prevent or at least reduce the drop in confidence when problems occur for real.

A point not very often heard when the one V's two crew arguments are discussed, is the strong psychological benefit of being accompanied by another crew-member at night or in difficult circumstances. Somebody to share the incertainties and the fears - what would Freud say to that?

Location information. The tendency, when engaged in low flying, for pilots to locate themselves because the outside world <u>appears</u> to tie in with where they are expecting to be is psychologically very strong, particularly in poor weather - therefore a very basic uncluttered display (such as the Tornado TV tab C plan format) is a real benefit and comfort. This shows a simple plan of the flight path with a symbol indicating the relative position of the aircraft.

Philosophy of Automation

This is another area which is often discussed by operational crews and usually results in a split between those who are for full automation and those who are against, with the in-betweens wanting a degree of automation but with an over-ride facility.

As this is another subject on its own and time does not permit an in depth coverage. I would summarise the philosophy of automation as follows:-

For:-

- Increased efficiency/accuracy in performing some tasks such as Terrain Following, Weapon Release, Track/Height/Speed hold.

- Relief of workload during Terrain Following, Wing Sweeping (in a variable geometry aircraft) and deployment of high lift devices in combat.

Against:-

- Psychological factor of a crews preference for 'self-reliance' and 'freedom of choice' can be very strong.

- Reliability. Automation inevitably means a higher degree of complexity over a non automatic system and which must reduce reliability to some degree.

It is of vital importance that automatics are capable of being checked for serviceability and that an override capability is provided, for both safety and psychological reasons.

Spatial Disorientation

Most, if not all the current generation of combat aircraft are flying with an equipment which is generally considered to be one of the major improvements in cockpit design in the past decade. - I refer to the Head-up Display (HUD). Pilots are unanimous in their opinion of the high value of this equipment, particularly during operational flying.

However, as with most advances/improvements some new factors/situations arise which are largely unforeseen and I think pilot reports of spatial disorientation when using the HUD come into this category.

The disorientation has usually been experienced when flying on a fully serviceable HUD and in what is generally termed as "gold-fish bowl" conditions, in other words, general haze with no visual horizon. In all but a few cases the disorientation has occured on transferring from visual cues to HUD and only overcome by concentration on the head down display (HDD). Some did not dispel the feeling of disorientation until they have regained visual conditions (VMC).

Disorientation, of course, is nothing new. However, the ease with which pilots can become disorientated when flying on a fully serviceable HUD needs wide publicity and methods of avoiding or overcoming covered in briefing at the Operational Conversion Units stage of training.

Another reported HUD phenomenon, and only by a very limited number of pilots is the re-focusing of the eyes necessary to either visually acquire a target through the HUD or to 'read-off' HUD information. This indicates that the primary design concept feature of the HUD that enables the pilot to see his HUD symbology superimposed on the outside world at infinity and therefore not requiring refocusing of the eyes is not true at all time or for all pilots.

Detachment Phenomenon

Although I personally have associated this with the "trussed chicken" feeling (particularly with pressure clothing, and pressure helmets and high altitude flying) apparently recent aircrew reports have shown that this can also occur with a clear helmet visor in the lowered position. The occasions reported have been when flying instrument approaches using HD instruments.

Reflection from the surface of the visor interfering with the pilots view of his instruments, leading to a strong feeling of detachment from what was happening. Which in one case was inaccurate flying with the pilot finding great difficulty in summoning the interest and effort to do anything about it.

Summary and Conclusions

I have welcomed the opportunity to stand in front of such a distinguished audience and to help to close the loop from the aircrew back to the designer, a loop which is vital if we are to continue to make the man/machine relationship more complementary and compatible.

Only a few Human Factors aspects of high speed, low level flying have only been touched on by this paper, but an effort has been made to highlight areas where in the authors opinion, supported by discussion with other aircrew, further thought and study is required and hopefully will result in an improved relationship between man and machine.

ADDRESSING HUMAN FACTOR OPTIONS IN CONCEPTUAL DESIGN

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SUMMARY

Recent experience with emerging Air Force systems has highlighted the importance of sound human factors implementation throughout all development phases ranging from conceptual design through development, test, and operational use. In general, new systems are characterized by technology advances "across-the-board" in sensors, flight control, and fire control, as well as the traditional flight vehicle technologies associated with aerodynamics, structures, and propulsion. For example, the rapid advance of avionics technology has greatly contributed to the operational capability of emerging fighter systems such as the Air Force F-16. Concurrent with this transition of technology into systems is the need for careful attention to aircrew integration throughout the development cycle, because a major system design goal is always to render the system usable to the operational aircrew. This paper emphasizes again the interplay of human factors technology with system design disciplines during the conceptual phase of development. This renewed focus is warranted because, while the pace of technology is rapidly advancing, it is important that the Air Force avail itself of the most recent technology and, via the exercise of new design tools, evolve better aircrew systems. Not only must aircrew systems be compatible with human capabilities and limitations, but they should be capable of being gracefully reconfigured in order to adapt to changes as subsystems evolve with time. By interacting with the trade-off process of conceptual design, human factor design/integration options can be evolved to obviate potential problems such as excessive aircrew workload. Addressing these options sufficiently early in development can avert potential problems well before the many system and hardware constraints are established. Given the long life cycle associated with weapon systems, costly retrofit and refit engineering changes must be minimized. The Air Force F-16 multirole fighter is the most recent system to benefit from a renewed focus on human factors. Such design features as a full bubble canopy for unobscured vision, fly-by-wire primary flight control system, modified ejection seat position for better comfort and G-relief, and the hands-on-throttle-and-stick concept for improved subsystem management are examples of the benefits of addressing human factor options in conceptual design. Further, continued attention in this area is needed in subsequent development phases for advanced systems as operational roles and aircrew systems are refined to meet multinational requirements. The Air Force Aerospace Medical Research Laboratory, in concert with other Air Force Laboratories, is taking advantage of lessons learned from projects such as the F-16 to develop and refine the design tools and methods for a timely insertion of human factors technology to meet the needs of future high performance aircraft.

INTRODUCTION

The importance of attention to human factors at the outset of design was recently affirmed in the NATO/AGARD community at the 1977 Multi-Panel Symposium on Fighter Aircraft Design (1). Implementing a sound human factors program, however, is a complicated issue that is related to the lengthy development time from concept to operations, to the maturity and acceptance of emerging technology to meet operational needs, and to the expected cost and performance design goals. Until recently, the major emphasis on human factors in system development was deferred to later stages of the development cycle; yet, changes in the process of major systems acquisition have reemphasized the need for innovation and competition in developing alternative concepts throughout the entire acquisition process. These changes have provided an opportunity for renewed attention to human factor options in conceptual design. A sound human factors implementation program, applied sufficiently early, can reap potentially great rewards by enhancing aircrew effectiveness and reducing development cost. This paper places a renewed emphasis on the interplay of human factors technology with system design/integration disciplines during the concept phase of development. This approach, although not restricted in application to high performance fighter aircraft, is discussed below in relation to the development process, the transition of technology, and potential future impact on fighter weapon systems. Selected design/integration features of the Air Force F-16 system illustrate the benefits which can result from addressing human factor options early in design. Finally, an effort currently underway at the Aerospace Medical Research Laboratory is described which attempts to further develop the design tools and methodologies which can be applied to the enhancement of aircrew capability with future high performance fighter systems.

DEVELOPMENT PROCESS

Development leading to the acquisition of major Air Force systems is a long process. For fighter aircraft, it is not unusual for more than ten years to elapse from the completion of conceptual design until the system attains maximum quantity rate of production. Past experience with Air Force fighters, such as the F-4, indicates that service lifetimes on the order of 20-30 years for specific types of aircraft can be

expected. During this life cycle, systems can become modified to reflect expanded mission requirements, changing threat situations, and emerging technology such that derivative variants of an aircraft type can differ (especially from the aircrew standpoint) from the initial production configuration. In all such model refinements, continuous human factors engineering review is necessary. Further, for systems such as the F-16, which are developed for international use, multinational configuration commonality is needed to enhance system interoperability. Because this system acquisition life cycle is such a lengthy process, it should be clear that design decisions early in development can preclude major engineering changes later in development. Hence, the design and integration of aircrew systems must not only be compatible with human capabilities and limitations, but they should also be capable of being gracefully reconfigured to adapt to changes as subsystems evolve with time.

The cycle for acquisition of major systems by the Air Force proceeds through four sequential phases depicted in Figure 1. Each phase begins with a formal review milestone, at which progress is gauged and the mission element need is reaffirmed. Although continuous attention to human factors is needed during the entire development cycle, a structured assessment of human factor options at the concept phase is particularly germane. In this regard, the so-called "front end" of the acquisition process, during which these options can be evaluated, is shown in Figure 2.

Air Force Laboratories participate in the system acquisition cycle in two important ways. First, direct support may be provided to other development agencies by furnishing technical expertise and analyses to support specific systems (especially when the unique capabilities of Air Force Laboratories are needed). Second, and perhaps more important, the Air Force Laboratories have the responsibility to undertake, sponsor, and guide the development of technology for future Air Force application. Hence, the Air Force Laboratories can contribute to the "front end" of system acquisition by establishing technology development programs that are time-phased, planned, and executed to yield proven technology for transition into future systems. In particular, promising human factor options can be explored in a systematic manner early in design to yield solutions to potential crew accommodation problems at the earliest development stage, where alternative solutions can be evaluated in a more cost effective manner. The process by which this can be accomplished is described herein. As noted in Figure 2, a key element in this regard is the exploration of alternate solutions to enhance crew and system effectiveness and reduce cost.

Placed on a time scale, the approximate schedule for design and evaluation of the F-16 multirole fighter is shown in Figure 3. It is noteworthy that system concepts originating in the early 1970s are planned for operational fruition in the mid-1980s. This time span of development highlights the importance of timely technology transition for future system application. With regard to human factors, laboratory programs can be devised in anticipation of future systems to develop and demonstrate the technology needed to enhance man-machine-mission effectiveness within available resources.

TECHNOLOGY TRANSITION

Related to the problems of long development cycles and system life cycles are issues of technology transition (Figures 4 and 5). The technology being applied to modern weapon systems is continually undergoing change, and the system development community must be in a position to anticipate this change and make judgments as to the applicability of candidate technologies (in terms of technical maturity or risk as well as performance and cost implications) for specific system developments. A recent overview of technology transition associated with Air Force fighter systems (2) outlined the methods for achieving this transition and recommended that a continuous system be established for identifying, evaluating, and tracking new technologies to facilitate the transfer of technology from the laboratory to systems application. That this problem is not trivial can be noted by reference to the development schedule for any major fighter system. If it requires, say, 10-15 years to develop a system from initial concept to operational status, and if there is no provision for inserting modern technology advances, it follows that the initial system usage will reflect technology that is 10-15 years old. This concern is particularly acute with regard to avionics technology which is presently experiencing high growth rates. Decisions to transfer emerging technology to future systems must be made on the basis of applicability, timing, risk, and cost. To confront this problem, recent developments of integrated digital avionics architectures hold the promise of permitting avionic updating through software reconfiguration. Corresponding advances in cockpit technology with regard to controls and displays are aimed at developing cockpits which may be updated through software revisions as avionic equipment subsystems are improved. The resulting ability for achieving ready cockpit changes to reflect technology improvement can be called graceful reconfiguration.

From a cockpit and human factors perspective, the future trend in fighter design is toward giving the aircrew a functional role of supervisory management rather than direct manual control by taking advantage of technology advances in various disciplines. Today's fighter systems have available an enormous amount of information, much of which must be assimilated by aircrews via antiquated display devices. This, coupled with the necessarily small panel space for fighter displays, poses an information management problem for tactical aircrews. Future high performance fighter systems must come to grips with this problem through the evolution of integrated information management systems as well as advanced controls and displays. Future systems may well witness selective, task-tailored presentation of information such that aircrews will be provided

data as needed, rather than furnishing all the information all the time. Added development of this technology is needed since it represents a departure from prior design practice.

Technology efforts are underway in Air Force Laboratories emphasizing the human factors associated with the gamut of tactical fighter operations and focusing on critical areas such as visual and sensor-aided target acquisition, aerial weapon delivery, coupled fire control and flight control techniques, and terrain following and terrain avoidance visual displays (to cite a few examples). Technology transition mechanisms must be developed to assure that the products from these technology programs can be available for and successfully integrated within future generation fighter systems. This transfer of technology in the human factors area is particulary difficult because really new technology (i.e., fundamental change in aircrew systems) must gain the acceptance of the operational user, not to mention skeptical program managers; this requires successful marketing as well as demonstrated technical achievement. Further, the human factors area is not analogous to improved equipment for which performance and cost goals can be established, and against which emerging hardware technology can be measured. For successful transfer to human factors technology, human and system performance gains must be quantified, the risk associated with such advances must be acceptable, and the cost implications must be favorable. Otherwise, the technology will not be included with future systems. Fortunately, these issues are becoming evermore apparent and the Air Force development community is planning, scheduling, and performing its research and development programs for eventual transition into new systems.

SELECTED F-16 FEATURES

The multirole F-16 fighter system has progressed from its early 1970s prototype rendition (i.e., YF-16) to the capable operational variants (F-16A and F-16B) now in production. During this development, the F-16 has undergone changes and, as flight experience is gained, added changes can occur (as is typical in the acquisition of major systems). Management of this change is the responsibility of the F-16 System Program Office. Although gradual refining and improving of systems is a normal development and operational process, certain features of the F-16 design have not undergone significant change because of human factors concerns that were applied early in development.

Originally designed to be a highly maneuverable, light-weight, low-cost, single-place fighter, the F-16 has developed into a capable modern weapon system for undertaking air-to-air missions and air-to-surface missions. Associated with the design goal of high maneuverability, achieved in part by low wing loading and high thrust-to-weight ratio, was the desire to maximize the pilot's external visibility. To accomplish this, the F-16 was equipped with a full bubble canopy (Figures 6, 7) which is presently of monolithic construction and provides unobscured visibility. This has proven to be a desirable design feature, providing the pilot with a full 360-degree visual capability. A similar bubble canopy of laminated construction is also being considered for improved durability and lower life cycle cost. Weapon aiming errors which are a result of canopy optical distortions have been minimized by the use of advanced fire control algorithms.

A second feature of the original F-16 design which reflects early human factor attention and which is being proven in development is the fully fly-by-wire flight control system with which the aircrews interact via hand and foot controls. A substantial amount of technology has transitioned from the Air Force Flight Dynamics Laboratory in this area, which (in addition to many other benefits) has resulted in improved flying qualities, making the aircraft extremely responsive to pilot command.

A third feature which has received favorable pilot critique is the position of the ejection seat with the backrest inclined at 30 degrees from aircraft vertical (as opposed to the "standard" 13-degree position). This, coupled with a somewhat raised heel rest line, has resulted in substantially improved aircrew comfort and G-relief as compared to, for example, the F-4 series fighter which employs a standard seating position. It is well known that human resistance to acceleration is related to the time integral of the accelerative force. Hence, it follows that an individual design which offers added comfort and G-relief should be favorably received. Two aspects concerning this issue are noteworthy. First, the departure from past practice regarding seat position was part of the original YF-16 design, in part because of the design emphasis on maneuverability. This reflects a measure of human factors attention early in development. Secondly, and also important, the F-16 is capable of sustaining high G-levels as a result of its high thrust-to-weight ratio. Since, historically, fighters have been flown to maximum limits, design features to minimize the effects of acceleration are desirable.

Finally, some comments relative to the in-cockpit layout seem pertinent. The F-16 cockpit is not large. Figure 8 is a depiction of one of the early development versions and is not meant to reflect an accurate F-16 control/display arrangement. To illustrate relative cockpit size, note (in Figure 9) that the area on the F-16 front panel available for display devices is less than half the equivalent area available with the F-15 fighter system. The F-16 employs side-arm mounted primary flight and throttle controllers. Similarly to a design approach used with the F-15 system, the F-16 employs the hands-on-throttle-and-stick approach which allows the pilot fingertip management of sensors and weapons. Thus, continuous control of power and attitude is preserved, the pilot's

vision need not come "into the cockpit" to search for switch locations, and (with training) sensor and weapon mode switches are instantly accessible.

This is not to say that all problems have been solved, nor that the F-16 is a perfect airplane. For example, in the life support and personal equipment area, problems arise due to the restricted cockpit volume noted above. Likewise, the demanding nature of certain missions, such as night and all weather attack, is characterized by substantial aircrew task workload. However, past experience indicates that, provided with good training and adequate systems, our tactical aircrews can cope with difficult situations. For the F-16, as noted above, the attention to human factors early in design has resulted in selected design features that offer enhanced crew compatibility. That these features have survived intact this far in development is evidence supporting the premise herein that improved systems can be obtained by early development attention to human factors.

The challenge for the future is to take advantage of lessons learned in developments such as the F-16 and structure, prioritize, and schedule future research and development activity with full consideration to system development cycles and technology transition issues so that advanced human factor design options are available at the outset of future system development. To this end, laboratory programs as discussed below have been established to provide such design options.

FIGHTER/ATTACK CREW ENHANCEMENT

A key idea throughout this discussion is providing options (i.e., alternative approaches) for configuring aircrew systems. This is important because, in today's budget-constrained environment, planners and developers must consider the prime issues associated with affordability. Since the available funding for new systems is limited, it is practical to include just the essential technology options as opposed to other available options that are merely desirable. This is to insure that technology is applied only because it is truly needed. From a human factors perspective, it is incumbent on the research and development community to anticipate future system needs and apply human factors engineering design tools to yield man-machine integration options in advance of system development. This requires a commitment of resources to develop and refine these design tools as well as to apply them.

To illustrate an approach by which human factor options can be defined and assessed to interact with the conceptual design phase of development, this section describes activity underway at the Aerospace Medical Research Laboratory directed toward enhancing crew effectiveness for fighter/attack systems maturing post-1985. Planning for this activity began in 1975 when it became apparent that certain fighter systems would approach the end of their service lifetimes in the late 1980s. To replace these systems either with entirely new systems or with upgraded variants of existing systems to be introduced in the late 1980s, it seemed clear that supportive human factors technology development should begin immediately, given the system acquisition cycle and technology transition issues noted above. Definition study contracts were placed with industry to delimit the problem, emphasizing visual display integration options for 1985-1990 fighter aircraft. These studies are being succeeded by follow-on activity (about to begin) which will develop, evaluate, and transition the human factor options which emerged from the earlier definition efforts. It should be noted that this overall program was planned from its inception to transfer the technology evolved herein in the form of design recommendations and data in time for system planners and developers to make rational choices associated with aircrew systems for post-1985 fighters.

Integrative in nature, this program is outlined in Figure 10. The objectives of the definition phase and study ground rules are shown in Figures 11 and 12. Concurrent with the expected role for this system, emphasis was placed on the traditional tactical missions of close air support and air interdiction (both shallow interdiction and deep strike), with secondary emphasis on the counter air mission. It was assumed that such a system would retain defensive counter air capability for self-protection. Central activities during the definition phase were to develop a data base and define technology options which involved estimating the maturity of aircraft and avionic concepts in light of expected weather, geography, threats, supporting subsystems, mission analyses, weapons and tactics. The scope of the data base formation is shown in Figure 13. It should be clear that the factors to be considered in developing improved cockpit systems are diverse and that the cockpit cannot be designed in isolation from the rest of the system.

This study was structured by four sequential tasks. First, the data base was analyzed to:

a. Accomplish detailed mission analyses.

b. Identify sensor, avionics and weapon technology to meet mission requirements.

c. Identify display requirements dictated [illegible] iable technology options.

d. Identify available display technology to meet display requirements.

This involved functional analysis of mission needs, flight profiles, weapons, sensors, avionics, aircrew complement, and aircrew roles.

The second task used these data to assemble in detail the expected aircrew information requirements by mission phase for each tactical mission considered. Level of detail considered can be inferred by the phases of flight shown as Figure 14, since each phase (for example, penetration) was itself analyzed in detail from the aircrew standpoint.

The third task involved the synthesis of candidate display arrangements, one of which is shown as Figure 15. Note the reliance in display device technology on electronic displays. These studies confirmed that cathode ray tube (CRT) devices should be preeminent through the 1980s, even though progress is rapid in the technology associated with solid-state, digitally addressed flat panel devices which may eventually replace the CRT. Figure 16 illustrates the level of detail in which display hardware technology was analyzed. Other technology areas (such as sensors, weapons, communication and navigation equipment, etc.) were reviewed in similar detail.

The final task explored techniques by which optional cockpit approaches can be evaluated in advance of system development. Various evaluative techniques including interactive, real-time, man-in-the-loop simulation of tactical missions are being considered. The important point, however, is that evaluation of human factor options (including visual displays, as indicated in Figure 17) is paramount in establishing the relative value of competing designs and, equally important, in furnishing design guidance for future application.

By being in position to anticipate future operational requirements, many of the human factor issues can be resolved well in advance of hardware development. Though this technique is now being applied to future high performance aircraft, there is an expectation that this approach is generalizable to other than tactical systems. Figure 18 illustrates select mission areas of Air Force interest. Future systems devised to satisfy mission needs in these areas, given adequate program resources and management direction, can also be expected to benefit by a program of addressing human factor options in conceptual design.

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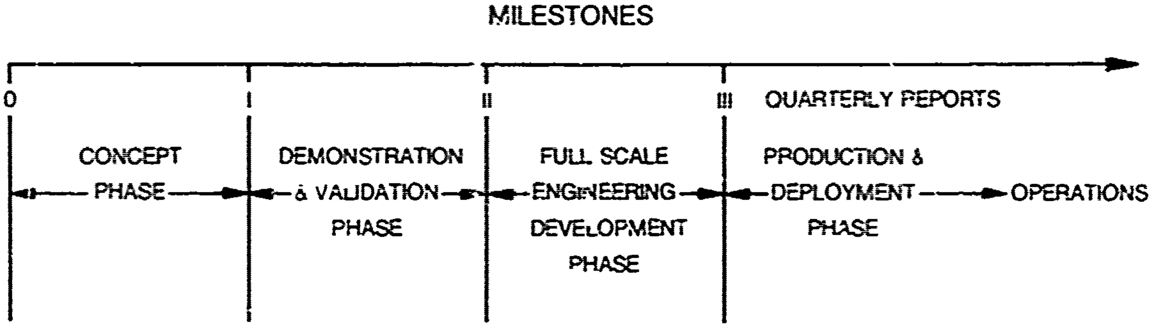

FIGURE 1 MAJOR SYSTEM ACQUISITION (DOD DIRECTIVE 5000 1, 18 JAN 77)

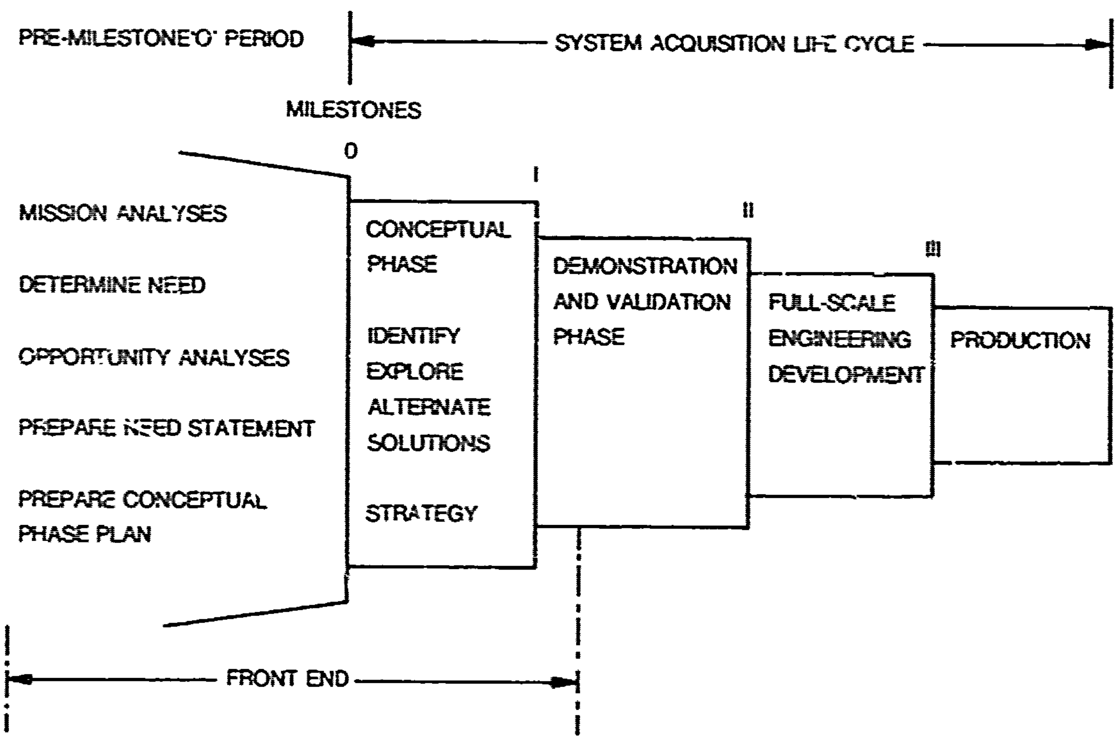

FIGURE 2. FRONT END OF THE ACQUISITION PROCESS

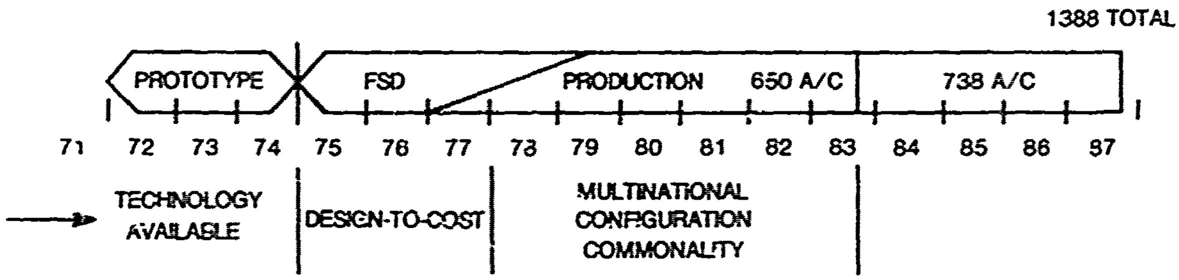

FIGURE 3. F-16 DESIGN EVOLUTION

- LENGTHY ACQUISITION CYCLE
- PACE OF TECHNOLOGY CHANGE
- PAYOFF
- TIMING
- RISK
- COST
- TRANSITION MECHANISM
  - THROUGH GOVERNMENT
  - THROUGH INDUSTRY

FIGURE 4. TECHNOLOGY TRANSITION ISSUES

- TECHNOLOGY IS SUBJECT TO CHANGE
- TECHNOLOGY STATUS

  RESEARCH
  DEVELOPMENT (EXPLORATORY)
  DEVELOPMENT (ADVANCED)
  DEVELOPMENT (ENGINEERING)
  CONCEPT PHASE
  DEMONSTRATION PHASE
  FULL SCALE DEVELOPMENT PHASE
  PRODUCTION PHASE
  OPERATIONAL TEST AND EVALUATION
  OPERATIONS

  LABORATORIES
  PRODUCT DIVISIONS
  OPERATIONAL USING COMMANDS

- PLANNING LABORATORY PROGRAMS FOR TRANSITION

FIGURE 5 ROLES IN TRANSITION

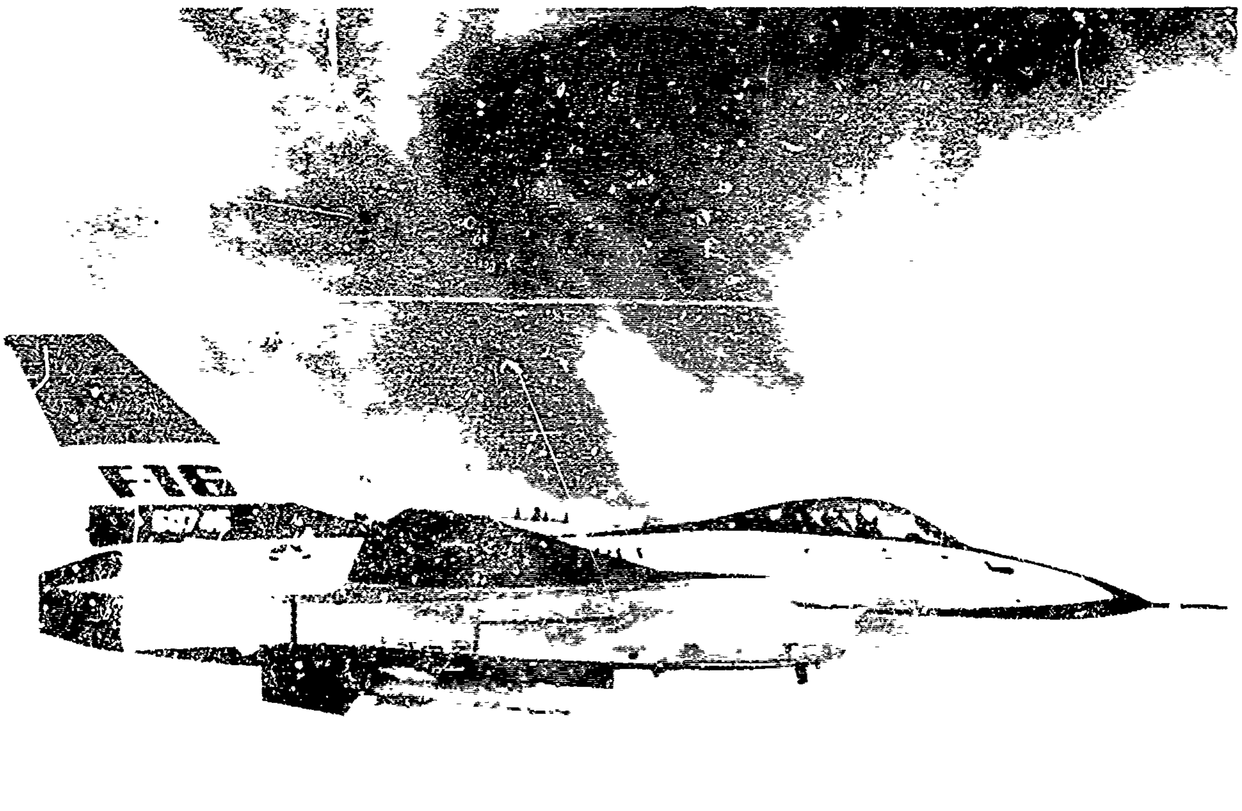

FIGURE 6 F-16 MULTIROLE FIGHTER

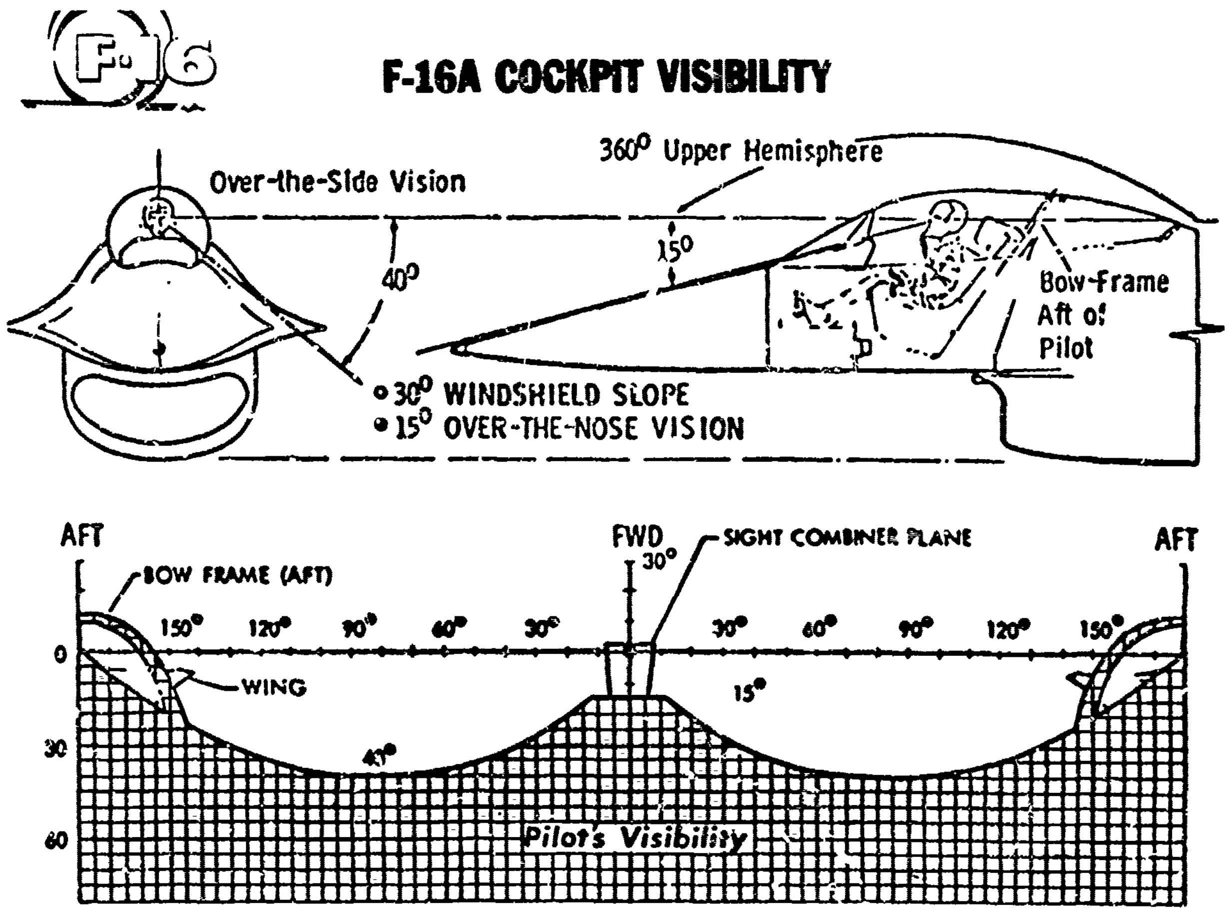

FIGURE 7. HIGH VISIBILITY F-16 CANOPY

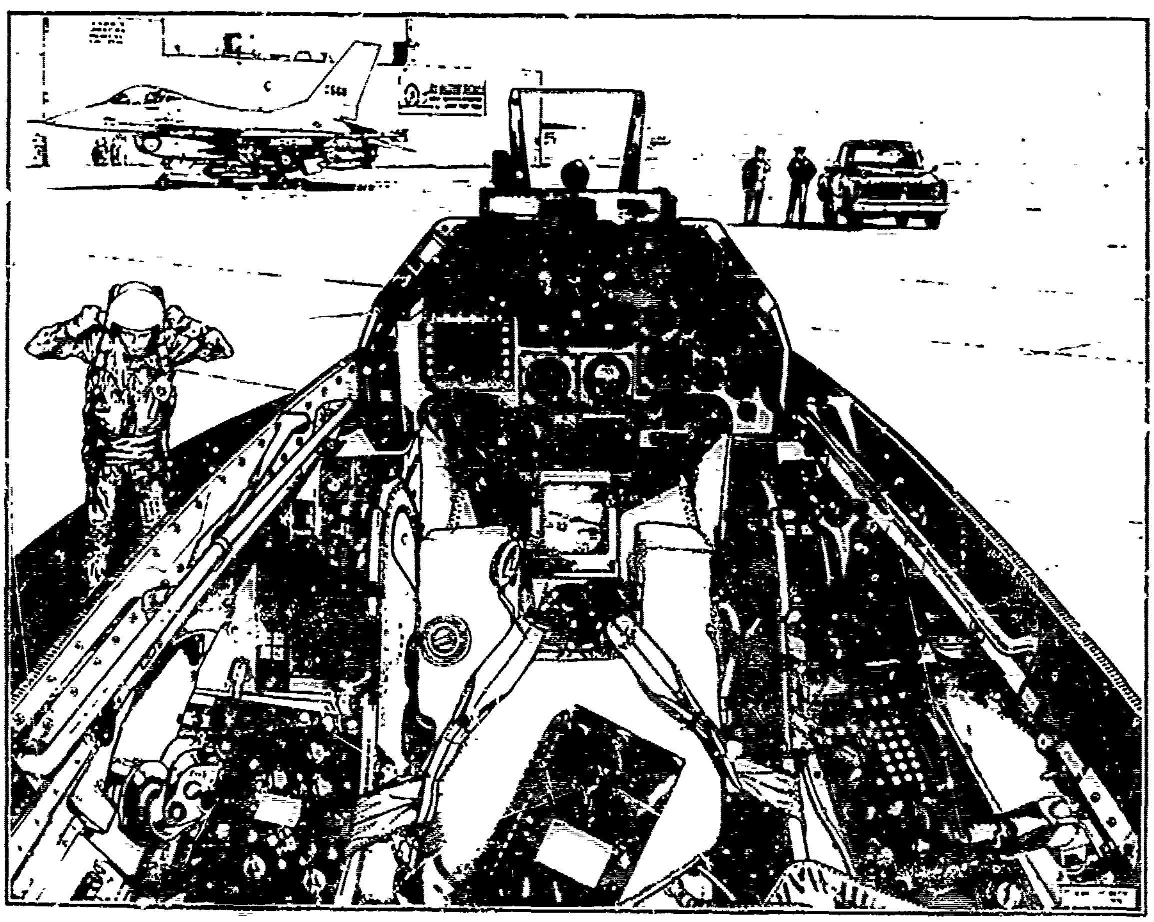

FIGURE 8. GENERAL DYNAMICS F-16

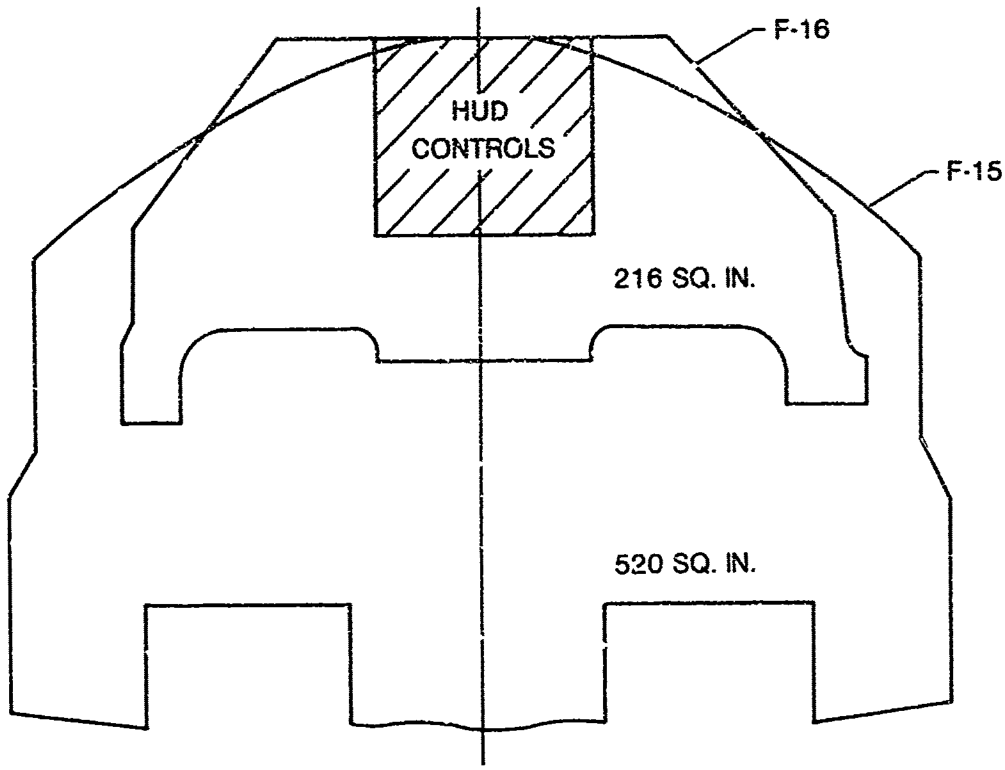

FIGURE 9. PANEL COMPARISON

OBJECTIVE	DEVELOP AIRCREW INTERFACE METHODS FOR POST-1985 FIGHTERS
APPROACH	CONTRACT EXPLORATION OF TACAIR CREW ENHANCEMENT

- DEFINITION PHASE
  - ASSESS DEVELOPMENT PLANS
  - DEVELOP DATA BASE
  - DEFINE TECHNOLOGY OPTIONS
- DEVELOPMENT PHASE
  - EVOLVE DESIGN TOOLS
  - ACCOMPLISH PRE-DESIGN TRADE-OFFS
- EVALUATION PHASE
  - COMPARE FIGHTER ENHANCEMENT OPTIONS
- TRANSITION PHASE
  - IMPACT EMERGING SYSTEMS

PROGRAM IDENTIFIER: 62202F/7184/718419

FIGURE 10. INTERFACE CRITERIA FOR ADVANCED TECHNOLOGY AIRCRAFT

(1) DEFINE PROBABLE ATTACK/FIGHTER MISSIONS AND BATTLEFIELD (1985-1990)

(2) DETERMINE CREW INFORMATION REQUIREMENTS

(3) DEFINE PROMISING DISPLAY INTEGRATION OPTIONS (1985-1990 CREW STATION)

(4) DEFINE DISPLAY EVALUATION FRAMEWORK (FUTURE STUDIES)

FIGURE 11. OBJECTIVES

- CENTRAL EUROPEAN THEATER
- 1985-1990 OPERATIONS
- TRADITIONAL TACTICAL MISSIONS
- BROAD RANGE OF THREATS
- DAY, NIGHT, ALL WEATHER
- COMMAND/CONTROL ENVIRONMENT
- STANDOFF TYPE WEAPONS (NON-NUCLEAR)
- SENSOR, SIGNAL PROCESSOR ADVANCES
- PROJECTED DISPLAY DEVICE MATURITY
- DETAIL ANALYSIS OF SUBSET OF ALL POSSIBLE MISSION/SYSTEM COMBINATIONS
- SINGLE PLACE, TWO PLACE CREW SIZE

FIGURE 12. VISUAL DISPLAY INTEGRATION STUDY GROUND RULES

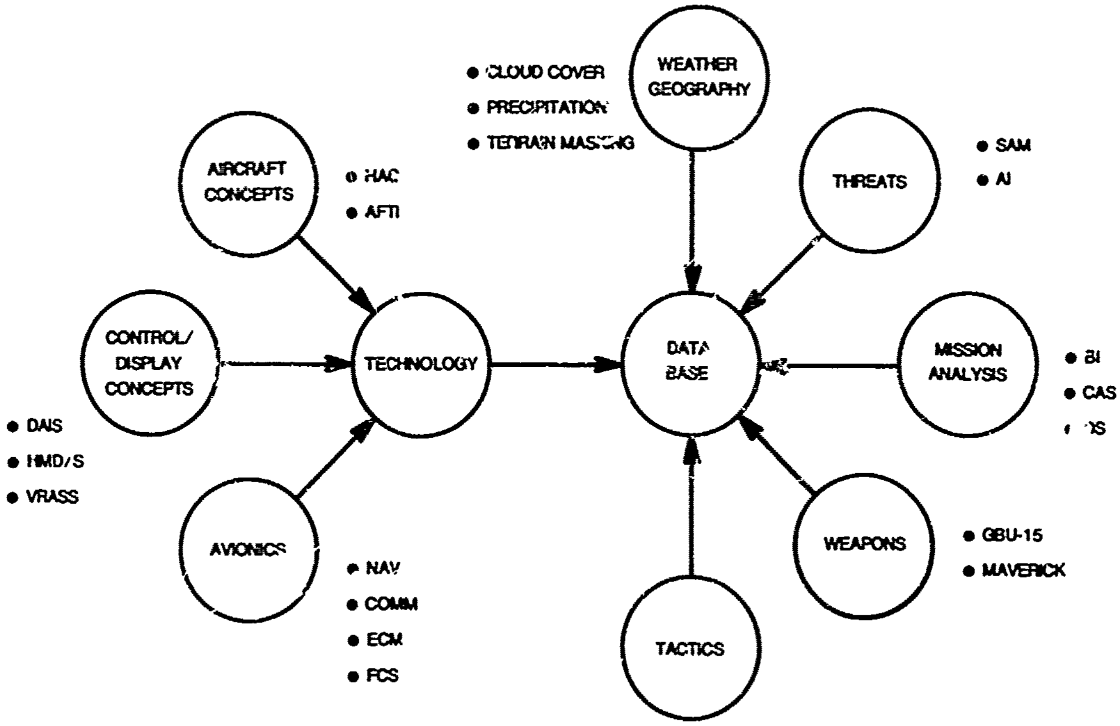

FIGURE 13. STUDY DATA BASE

1. PREFLIGHT - ALL AIRCREW FUNCTIONS LEADING UP TO BUT NOT INCLUDING TAKEOFF.

1.1 MISSION PLANNING
1.2 PREFLIGHT
1.3 START AND SYSTEM CHECKS
1.4 TAXI
1.5 ARMING
1.6 TAKEOFF

2. IN-FLIGHT - ALL FLIGHT ACTIVITIES BEGINNING WITH TAKEOFF AND CONCLUDING AT THE TERMINATION OF THE LANDING ROLL.

2.1 CLIMB TO LEVEL OFF
2.2 CRUISE
2.3 LOITER
2.4 RENDEZVOUS AND AIR-TO-AIR REFUELING (AAR)
2.5 COORDINATION
2.6 MISSION RENDEZVOUS
2.7 PENETRATION
2.8 THREAT WARNING
2.9 DETECTION
2.10 LOCATION
2.11 IDENTIFICATION
2.12 DECISION
2.13 EXECUTION
2.14 ASSESSMENT
2.15 TERMINATION
2.16 EGRESS
2.17 CRUISE
2.18 RENDEZVOUS AND AIR-TO-AIR REFUELING (AAR)
2.19 REENGAGE
2.20 RETURN TO BASE
2.21 DESCENT
2.22 APPROACH
2.23 LANDING

3. POST-FLIGHT - ALL MISSION RELATED ACTIVITIES BEGINNING AFTER THE COMPLETION OF THE LANDING ROLL AND ENDING WHEN THE AIRCREW IS FREE TO PERFORM OTHER DUTIES OR PURSUE PERSONAL INTERESTS.

3.1 DE-ARM
3.2 TAXI
3.3 SYSTEM CHECKS
3.4 SHUTDOWN
3.5 POST-FLIGHT
3.6 DEBRIEF

FIGURE 14. MISSION REQUIREMENTS: PHASES OF FLIGHT

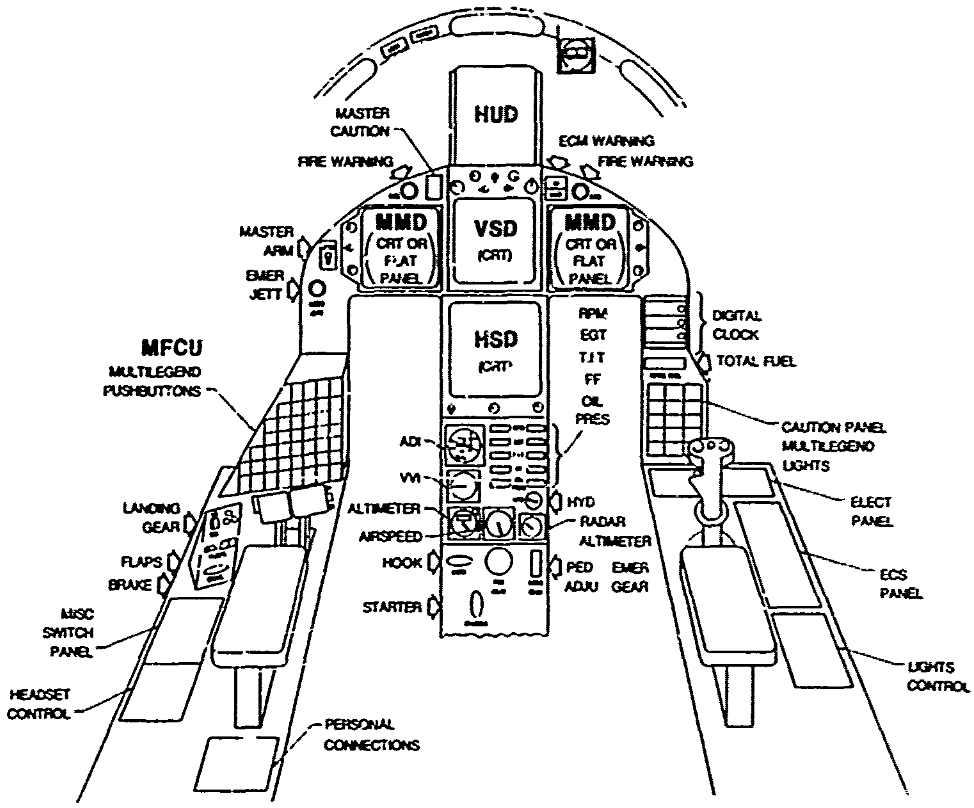

FIGURE 15. CANDIDATE EVALUATION CONTROL/DISPLAY LAYOUT

PARAMETER	PLASMA PANEL	ELECTROLUMINESCENCE (THIN FILM)	LIGHT EMITTING DIODES	LIQUID CRYSTAL	CRT
RESOLUTION	30-60 EPI	20-50 EPI, LARGE PANELS 500 EPI, SMALL PANELS	30-50 EPI	100 EPI, LARGE PANELS 588 EPI, SMALL PANELS	120-1600 EPI
BRIGHTNESS	>30-60 FT L	>30 FT L	>100 FT L	AMBIENT DEPENDENT	>30-1000 FT L
CONTRAST	≥20:1 BINARY	≥:0:1 FULL VIDEO	100:1	20:1 FULL VIDEO	20:1 FULL VIDEO
DISPLAY SIZE	≤ 1024 ELEMENTS 17 INCH SQ (AC DRIVEN)	240 ELEMENTS, 6 INCH 500 ELEMENTS, 1 INCH	25[illegible] ELEMENTS 6 [illegible] SQ	350 ELEMENTS, 3.5 IN 600 ELEMENTS, 1 IN	480-830 ELEMENTS 1.25 INCH SQ
COLOR	PRIMARILY NEON ORANGE FULL COLOR POSSIBLE	PHOSPHOR DEPENDENT FULL COLOR POSSIBLE	RED, GREEN AND YELLOW ALSO AVAILABLE	PRIMARY BLACK/WHITE BUT CONTRASTING COLORS ARE AVAILABLE	PHOSPHOR DEPENDENT, DISCRETE COLORS ALSO
POWER REQUIREMENTS	200-300W	10W	1.5-2.0W/cm² @ 1.5-2.0 VOLTS	5μW/cm² TO 1.0 mW/cm² @ 3-15 VOLTS	100 WATTS
THICKNESS	<1 INCH	<1 INCH	<1 INCH	<1 INCH	≈12-18 INCH
WEIGHT	50 LBS	–	–	–	UP TO 50 LBS
ENVIRONMENT	RUGGED	RUGGED	RUGGED	RUGGED BUT TEMPERATURE LIMITS	RUGGEDIZED
ASPECT VIEWING	WIDE ASPECT	UNIFORM, WIDE ASPECT	SLIGHT GAIN BUT BASICALLY UNIFORM	RESTRICTED	UNIFORM WIDE
TIME CONSTANTS	STD VIDEO (DC DRIVEN)	COMPATIBLE WITH STD VIDEO	COMPATIBLE WITH STD VIDEO	10-500 MS (WITH SCAN CONVERTER LC CAN DISPLAY STD VIDEO)	3-10MHZ STD VIDEO
STORAGE/REFRESH	YES (AC DRIVEN) NO (DC DRIVEN)	YES, BUT IS CONFIGURATION DEPENDENT	NO	LIMITED STORAGE	NONE (STORAGE CRTs ARE AVAILABLE
RELIABILITY MAINTAINABILITY	100,000 HRS LRU	1,000 TO 10,000 HRS LRU	10,000 TO 100,000 HRS LRU	20,000 HRS LRU	15 TO 15,000 HRS LRU
STATUS	OPERATIONAL COMMERCIALLY AVAILABLE	LABORATORY DEMONSTRATION MODELS	COMMERCIALLY AVAILABLE/OPERATIONAL	OPERATIONAL LABORATORY DEMONSTRATION MODELS	OPERATIONAL

FIGURE 16. DISPLAY TECHNOLOGY COMPARISONS

PURPOSE

- VERIFY CONCEPTUAL UTILITY OF COMPETING DESIGN CONFIGURATIONS
- PROVIDE DESIGN GUIDELINES ON OPERATOR/ DISPLAY INTERFACE

FIGURE 17. EVALUATION OF VISUAL DISPLAY SYSTEMS

- STRATEGIC OFFENSE
- STRATEGIC DEFENSE
- TACTICAL AIR TO GROUND
- TACTICAL AIR SUPERIORITY
- RECCE/INTELL
- AIRLIFT
- TRAINING

FUTURE SYSTEMS

FIGURE 18. MISSION AREAS

FACTEURS HUMAINS DES MISSIONS DU MIRAGE 2000.

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RESUME

Comme les avions modernes, le Mirage 2000 se caractérise essentiellement par sa grande maniabilité, son aptitude à évoluer en haute altitude, l'allègement de la charge de travail de son pilote. Ces trois caractéristiques essentielles nécessitent une adaptation du pilote à son avion.

La grande maniabilité suppose des variations très brutales des accélérations intenses que subira le pilote. La tolérance des accélérations répétées est encore mal connue, surtout à long terme et par conséquent, à défaut d'entraînement, la sélection doit être rigoureuse.

Les effets physiopathologiques de la haute altitude sont mieux connus et une protection efficace peut être proposée.

Les chances de réussite des missions ne seront réelles que si le pilote dispose d'un environnement confortable, cela suppose des études ergonomiques du siège, des commandes, des équipements de protection et de la ventilation de la cabine.

1. - INTRODUCTION

Essentiellement défini pour satisfaire les exigences opérationnelles de défense et de supériorité aérienne, le Mirage 2000 doit progressivement remplacer le Mirage III qui équipe les forces aériennes françaises depuis près de vingt ans.

Comme pour le Tornado et comme pour le F 16, les caractéristiques en vitesse, altitude de vol et accélérations du Mirage 2000 ne sont pas foncièrement différentes de celles d'avions actuels, plus anciens.

On peut, dès lors, se poser la question de savoir si le Mirage 2000 pose des problèmes humains nouveaux et dans quelle mesure les données classiques de la médecine et de l'ergonomie aéronautique pourraient être remises en cause par l'utilisation de ce type d'avion.

Au cours de cet exposé, nous essayerons de montrer que l'adaptation du pilote à son nouvel avion risque de poser des problèmes nouveaux, essentiellement parce que l'évolution des techniques a fait disparaître certaines limitations du domaine d'utilisation de l'avion.

Ces problèmes ergonomiques sont essentiellement liés :

- aux accélérations longitudinales soutenues et de haut niveau ;
- à la charge de travail mental élevée que nécessite le pilotage et l'utilisation du système d'armes ;
- à l'environnement de la très haute altitude.

Il en découle la nécessité d'étudier des équipements de protection efficaces mais confortables, un environnement climatique adéquat et de réaliser un entraînement ou, du moins, une sélection rigoureuse du personnel navigant servant ces nouvelles machines.

2. - LES ACCELERATIONS

L'intensité des accélérations dont est capable le Mirage 2000 ne dépasse en valeur absolue que de quelques "g" les valeurs connues sur les avions actuellement en service. Elles pourront, par contre, être appliquées beaucoup plus longtemps et surtout s'établir ou disparaître très brusquement.

L'avion devient beaucoup plus maniable et les accélérations seront présentes dans tout son domaine d'utilisation. Avec un Mirage III à 50.000 pieds, 5 g ne pouvaient être obtenus que pendant une durée très brève, avec un Mirage 2000, cette accélération et même des accélérations plus élevées peuvent être réalisées pendant une longue durée à la même altitude.

La caractéristique principale des avions de nouvelle génération nous semble donc être leur très grande maniabilité avec comme corollaire pour le pilote le passage répété et brutal d'une intensité d'accélération à une autre, supérieure ou plus faible.

C'est là que la dérivée de l'accélération ou nombre de jolt prendra toute sa valeur. Son importance n'avait jusqu'à présent été pleinement comprise que pour l'étude des effets physiopathologiques des accélérations de durée très brève, en particulier dans le domaine du siège éjectable et des impacts de crash.

Les effets des accélérations longitudinales sur les grandes fonctions physiologiques, cardio-vasculaires, respiratoires, sur le système nerveux central et les capteurs sensoriels, sur la performance psycho-intellectuelle et motrice, sont actuellement bien connus grâce aux nombreuses expérimentations menées dans les centres de recherche et grâce à l'expérience vécue par de nombreux pilotes.

La tolérance humaine vis à vis de ce facteur de stress du vol est exactement évaluée et des moyens de protection relativement efficaces sont à la disposition des personnels.

Cela est vrai des accélérations d'intensité moyenne, établies relativement doucement et n'excédant qu'exceptionnellement quelques dizaines de secondes.

Il en va tout différemment des accélérations soutenues pendant des temps dont on imaginait même pas la possibilité de survenue en aéronautique et surtout des accélérations très rapidement établies, sans cesse variant en direction ou en module, réalisant de véritables pics de quelques secondes sur une ligne de base de faible intensité.

Cela s'explique par le fait qu'il n'existe encore que fort peu de pilotes ayant une grande expérience d'une mission au cours de laquelle l'avion serait presque en permanence sous facteur de charge non stabilisé et aussi par le fait que les moyens de simulation de tels profils d'accélération sont encore rares.

Si quelques laboratoires privilégiés et disposant des moyens de simulation nécessaires à l'étude des accélérations de haute intensité ont pu décrire, le plus souvent, sur modèle animal, quelques effets physiopathologiques cardiaques survenant à partir de + 7 Gz, tels qu'hémorragies sous endocardiques ou dégénérescence myofibrillaires, il en est fort peu qui décrivent les effets physiopathologiques ou anatomopathologiques des accélérations d'intensité plus modeste mais soutenues pendant quelques dizaines de minutes.

A cet égard, il faut rappeler que les accélérations de longue durée présentent le grand intérêt de permettre une bonne exploration de la fonction cardio-vasculaire, même si elles ne sont qu'un mauvais modèle de représentation des missions opérationnelles.

A fortiori on ignore encore beaucoup des réponses physiologiques ou des troubles que pourrait présenter l'homme soumis à des accélérations itératives de forte intensité pouvant atteindre + 8 g, évoluant sur un fond plus ou moins ondulant, dont on ignore d'ailleurs encore le niveau moyen et dont rien ne permet de dire qu'il demeurera longtemps figé.

Ce que l'on sait des effets pathologiques sur l'homme, des accélérations soutenues de grande intensité, peut être ainsi résumé :

Il s'agit essentiellement de troubles vasculaires, ce sont des hémorragies pétéchiales cutanées qui apparaissent dans les zones où le vêtement anti-G n'exerce plus de pression. Elles sont parfois assez impressionnantes par leur taille et leur couleur mais sont indolores et disparaissent totalement en quelques jours. Leur existence pose la question de la possibilité d'hémorragies sur d'autres organes avec des conséquences plus sérieuses. Ce sont aussi des oedèmes des pieds et des chevilles dus à l'élévation prolongée de la pression hydrostatique dans ces extrémités non protégées par le pantalon anti-G.

Au plan cardiaque, les anomalies électrocardiographiques sont maintenant bien connues. Elles sont fréquentes et peuvent apparaître même pour des accélérations d'intensité moyenne pour peu qu'elles soient longtemps soutenues.

Au cours des épreuves de sélection des candidats français aux vols du programme Spacelab, nous avons eu la surprise de découvrir, à l'issue d'un test en centrifugeuse de dix minutes sous une accélération stabilisée de + 3 Gz, des troubles du rythme chez des sujets jeunes, en bonne santé apparente, puisque déclarés aptes peu de temps auparavant par le Centre d'Expertise du Personnel Navigant. Il s'agissait soit de dissociation auriculo-ventriculaire de type Mobitz 1 ou 2, soit de tachycardies avec ou sans extrasystoles ventriculaires.

D'autres auteurs ont rapporté des blocs auriculo-ventriculaires, des rythmes bigeminés ou des altérations du tracé à type de dépression du segment ST ou de modifications de l'onde de repolarisation.

Ces perturbations du rythme peuvent être rattachées à une activité sympathique excessive. Celle-ci parait évidente lorsqu'on s'adresse à des sujets très jeunes, peu habitués à l'environnement d'un laboratoire et aux tests en centrifugeuse, où le plaisir du vol fait totalement défaut.

On peut craindre que la tachycardie orthosympathique ne soit à l'origine de l'élimination de jeunes sujets "faux positifs".

Mais il faut évoquer aussi des modifications de la position du coeur sous accélérations, les changements de répartition du volume sanguin central et de remplissage des cavités cardiaques.

Enfin, l'hypothèse d'un certain degré d'ischémie cardiaque ne peut être rejetée, puisqu'il est maintenant prouvé que le débit cardiaque et le volume d'éjection systolique est réduit de façon importante sous facteur de charge. D'ailleurs pour certains auteurs, la bradycardie parfois très importante, relevée dès l'arrêt de l'accélération, pourrait être un état présyncopal vaso-vagal entraîné par un défaut de remplissage du coeur.

En ce qui concerne la tachycardie, que l'on observe toujours et aussi bien chez des pilotes que chez les non navigants, elle augmente proportionnellement à la valeur de l'accélération jusqu'à 7 g, atteignant 180 c/mn. Au-delà l'accroissement est faible parce que le niveau maximum est pratiquement atteint.

L'importance de cette tachycardie ne doit pas être sous estimée, car elle semble avoir une valeur prédictive dans la tolérance aux accélérations et parce qu'il existe indubitablement chez l'animal, une corrélation entre fréquence cardiaque et importance des hémorragies sous endocardiques.

A côté des manifestations cardio-vasculaires, il existe sous accélération des perturbations de la performance. Même si elles ne reflètent que très indirectement la capacité fonctionnelle du système nerveux central, quelques points particuliers méritent d'être discutés, car ils nous paraissent importants pour la sécurité des vols et pour la conception des interfaces pilote-avion d'armes.

Les perturbations de la fonction visuelle sont connues dans leurs aspects élémentaires : diminution de l'acuité visuelle, rétrécissement du champ et difficultés d'exploration du champ perceptif.

On ne connait encore rien de la vision colorée sous facteur de charge, alors que les présentations de l'information commencent à faire appel au codage coloré.

Les mécanismes perceptifs sont largement perturbés. Les illusions sensorielles qui apparaissent à l'établissement comme à la cessation de l'accélération, liées aux stimulations maximales de l'appareil vestibulaire et responsables de la perte des références spatiales objectives, sont actuellement relativement connues. Mais, on n'a encore aucune donnée concernant les effets de champ et les jugements perceptifs qui sont à la base des comparaisons de largeur, de distance et des estimations d'altitude ou de vitesse relative.

On a récemment décrit des troubles de désorientation persistants plusieurs heures et jusqu'à un jour après l'exposition à des accélérations élevées de longue durée. Il s'agissait d'un phénomène de désadaptation des organes de l'équilibration lors de la cessation du stimulus.

Cependant, l'hypothèse de lésions mineures des organes otolithiques ne peut être rejetée. La disparition des troubles s'expliquerait alors par des mécanismes compensateurs centraux. Lorsqu'on sait l'importance que revêt le sens de l'équilibre dans les phases de combat,on ne peut être qu'inquiet de l'apparition de sensations vertigineuses.

Ces troubles labyrinthiques, déjà importants par eux-mêmes, conduisent secondairement à des attitudes et à des postures préjudiciables au rachis cervical.

En effet, pour se soustraire au vertige des accélérations, le pilote doit figer sa tête. On connait pourtant l'incidence des accélérations sur l'arthrose cervicale, pathologie du sujet jeune aggravée par la posture figée de la tête. Il y a là un véritable cercle vicieux, puisque l'arthrose cervicale est une étiologie fréquente des sensations vertigineuses.

Les effets directs, mécaniques des accélérations, touchent bien entendu les fonctions motrices, principalement leur coordination. Difficultés dans les atteintes gestuelles, difficulté de maintenir une position, à l'origine de difficiles problèmes d'ergonomie.

C'est ainsi que sous facteur de charge, la position neutre du manche est non seulement difficile à percevoir, mais difficile à tenir.

C'est ainsi, d'autre part, que le pilote soumis aux accélérations a tendance à tirer sur le manche. Lorsqu'il regarde à l'extérieur, il a tendance à incliner le manche du côté de son regard ou le pousser s'il regarde en bas. On peut se demander si dans ces conditions, un petit manche à efforts purs, répond au mieux au problème ergonomique ? Ce petit manche doit-il être à droite ? ou à gauche interfèrent alors avec la commande des gaz. Ne vaut-il pas mieux alors garder un manche en position centrale ? Mais il y a si peu de place pour lui dans la cabine.

Pour conclure sur ce thème, rappelons que les manches se sont aujourd'hui ornés d'une multitude de boutons et de commandes, de taille parfois réduite, qu'il n'est pas toujours aisé de manipuler lorsqu'on a de gros doigts recouverts de gants et que les accélérations rendent les mouvements fins extrêmement difficiles.

A l'issue de cet exposé, il nous parait indispensable de nous poser quelques questions concernant la tolérance de nos pilotes aux nouveaux profils d'accélérations, la protection que nous devons leur assurer, leur entraînement et leur sélection.

En ce qui concerne la tolérance, nous ne pouvons pas encore répondre de façon définitive, car trop d'inconnues demeurent,particulièrement en ce qui concerne les métabolismes ou les fonctions endocriniennes et les effets à très long terme.

Pour ce qui est de la protection,on peut d'ores et déjà assurer que les pantalons anti-G sont insuffisants, non parce qu'ils n'apportent aucune protection contre les accélérations élevées, mais parce que leur temps de réponse est trop long. Le profil des accélérations au cours du combat sera très vraisemblablement constitué de pics très brusques d'accélérations élevées. Il est donc à craindre que du fait de son inertie,

l'équipement n'entrera en jeu que beaucoup trop tard. Il n'est pas évident que l'on pourra beaucoup gagner sur le temps de réponse des valves, cela supposerait soit des débits d'oxygène prohibitifs, soit des asservissements complexes et de fiabilité douteuse.

Les essais de prégonflage du vêtement que nous avons réalisés au Laboratoire ne nous ont pas encore apportés les résultats que nous en attendions.

Nous ne sommes personnellement pas très optimistes sur la possibilité d'utiliser la respiration en surpression comme moyen de rétablir une distribution normale du volume sanguin central et un remplissage cardiaque satisfaisant,puisque cette méthode utilisée sous facteur de charge parait augmenter significativement les risques d'atelectasies pulmonaires.

Enfin, nous ne concevons pas très bien comment un pilote au combat pourrait longtemps bénéficier des manoeuvres d'expirations forcées et de contractions musculaires, type M1 ou dérivées, parce qu'elles nécessitent la flexion forcée en avant gênant la visibilité et augmentant le risque de vertiges, parce qu'elles sont très fatigantes, surtout si elles doivent être sans cesse répétées.

Il ne reste plus alors que l'espoir de transformer en partie l'axe d'application des forces d'inertie en inclinant les sièges. Avec un angle de 30° comme pour le YF 16, ou voisin de 27° comme pour le Mirage 2000 on obtient déjà de bons résultats. La possibilité de réaliser un siège encore plus incliné, se heurte à un impératif, celui de voir et à de très grosses difficultés techniques d'aménagement de la cabine, d'une part, et d'éjection du siège, d'autre part.

Il faut donc entraîner les pilotes. Cet entraînement pose toutefois des problèmes théoriques et pratiques.Dans de nombreux pays, ni les avions équipant les écoles des forces aériennes, ni les rares centrifugeuses humaines, ne sont capables de réaliser les profils d'accélération délivrés au combat par les avions de la nouvelle génération. Il y a là un problème d'équipement qui n'est pas pres d'être résolu.

Mais il y a peut être plus grave. On est en droit de se demander quel sera le gain de cet entraînement, compte tenu du fait que l'on connait mal la tolérance, que l'on ignore les effets des expositions répétées dans la journée, à fortiori tout au long de la carrière d'un pilote.

Puisqu'il est certain que ces accélérations intenses et soutenues mettent à rude épreuve l'organisme humain, ne doit-on pas craindre d'user en temps de paix des pilotes qui feront défaut à la guerre ? Et dans un conflit, combien de missions de combat un pilote effectuera-t-il ?

En ce qui concerne la sélection des pilotes appelés à servir ces avions, en l'état actuel de nos connaissances, nous pensons qu'elle doit être rigoureuse et s'adresser à des sujets jeunes.

Certes les examens médicaux cliniques et biologiques traditionnels doivent être maintenus car ils permettent un premier tri, mais nous avons vu qu'ils sont insuffisants puisque des sujets reconnus aptes peuvent présenter lors des tests en centrifugeuse des signes manifestes de désadaptation cardio-vasculaires.

La centrifugeuse constitue donc un moyen précieux de parfaire le bilan médical. Encore faudrait-il que les tests à utiliser soient bien codifiés pour rechercher une anomalie cardio-vasculaire et qu'ils soient proches de la réalité pour avoir valeur d'entraînement.

Au cours d'une conférence récente, qui réunissait au Canada les membres de l'OTAN, un projet de normalisation des tests de sélection a été mis sur pied. Ce texte suggère de soumettre le candidat, à une accélération de + 7 Gz établie avec un jolt supérieur à 1 g/s. Ce test sera arrêté et le pilote déclaré inapte si le rythme cardiaque dépasse 200 battements/mn, de même si le champ visuel subi une amputation de plus de 50 p. cent.

A ce propos, nous pensons que ce profil n'est pas réalisable avec toutes les centrifugeuses actuelles; qu'il est dangereux étant donné la corrélation positive qui existe entre les fortes tachycardies et les lésions du myocarde. Rappelons qu'une fréquence cardiaque de 220-âge correspond aux possibilités maximales cardiaques lors d'un exercice musculaire exhaustif.

Enfin, ce test n'est pas réaliste car on peut se demander qu'elle est la valeur au combat d'un pilote amputé de la moitié de son champ visuel.

Nous préférerions sélectionner des pilotes jeunes apres avis du commandement,car c'est en escadre, sur le terrain,que se recrutent dans la pratique les pilotes qui "tiennent" les accélérations. Ces individus subiraient alors un test en centrifugeuse. Test unique pratiqué pendant au moins dix minutes sous 3 ou 4 Gz avec surveillance permanente de l'électrocardiogramme, la fréquence ne devrait pas dépasser 160 à 180 c/mn, et du champ visuel.

3. - LA CHARGE DE TRAVAIL

Le Mirage 2000 diffère de ses prédécesseurs par l'importance de l'effort accompli pour soulager la tâche du pilote.

Si l'effort est couronné de succès, en ce qui concerne la tâche physique, il est beaucoup moins certain qu'il en soit de même de la tâche mentale.

L'acquisition automatisée et synthétisée des données présentées sur des scopes avec une symbolique colorée nouvelle, pose pour certains pilotes d'indéniables problèmes d'adaptation.

Certains auteurs ont signalé la survenue sous facteur de charge élevé, de périodes brèves mais périodiques, d'effondrement total des facultés intellectuelles. Ces "trous" bien analysés par WILKINSON sont interprétés comme une saturation des capacités de traitement du système nerveux central.

Faut-il en déduire qu'au cours de profils d'accélérations répétées de niveau élevé, le pilote serait périodiquement dans la quasi impossibilité d'effectuer une tâche psychique complexe ? La question est encore sans réponse, d'autant qu'il n'existe à notre connaissance aucune étude systématique de la période qui suit l'application de l'accélération. On sait pourtant que lorsque le système nerveux central a été soumis a une agression sévère, le retour à un niveau d'éveil normal n'est pas instantané. Les électro-encéphalogrammes montrent, par exemple, une persistance du ralentissement du rythme pendant 15 s ou plus après la cessation du stimulus.

Le travail sous simulateur permettra aux pilotes d'acquérir une bonne habitude des procédures et limitera sans doute la tâche lors de la mission. Mais le simulateur ne recrée pas toutes les conditions du vol. Il y a peut-être beaucoup à attendre des "g-seats" recréant chez le pilote l'illusion des accélérations.

4. - LA HAUTE ALTITUDE

Les missions effectuées jusqu'à 45.000 ft, ne posent aucun problème particulier pour le Mirage 2000. La pressurisation de la cabine dont le ΔP est de l'ordre de 30 KPa (4,27 psi), rétablit à 45.000 ft une pression cabine de 44,7 KPa, soit une altitude équivalente de 21.000 ft. A cette altitude l'inhalation au masque d'un mélange contenant 45 p. cent d'oxygène permet de maintenir une pression alvéolaire d'oxygène égale à celle que l'on obtient à 1.500 m en respirant l'air ambiant. En cas de perte de pressurisation, le régulateur est capable de délivrer la surpression d'oxygène pur nécessaire au maintient d'une pression alvéolaire suffisante pour éviter des troubles sévères d'hypoxie. Avec le régulateur choisi la respiration en pression positive limitée à 1 KPa est possible. Elle permettra d'isoler le pilote d'une ambiance ABC.

Pour ce qui est des missions accomplies jusqu'au plafond de l'avion, soit environ 80.000 ft, il a été nécessaire de prévoir une protection contre l'hypoxie et les risques de surpression pulmonaire, s'il y a décompression rapide accidentelle.

Cette protection est assurée par la pressurisation de la cabine dont le ΔP reste de 30 KPa (4,27 psi), jusqu'au plafond de l'avion, si bien qu'à 80.000 ft le régulateur délivre au masque un mélange enrichi en oxygène de façon à maintenir une pression partielle alvéolaire adéquate.

En cas de décompression si l'on veut éviter l'hypoxie fulgurante, il faudrait fournir au poumon de l'oxygène pur avec une surpression de l'ordre de 16 KPa (2,28 psi).

On sait qu'une telle valeur de surpression n'est pas tolérable au plan physiologique du fait de l'inconfort, des troubles respiratoires et vasculaires qu'elle entraîne et qu'elle n'est pas réalisable avec l'équipement utilisé en basse altitude du fait des fuites du masque.

Par ailleurs, la nécessité de diminuer le rapport de pression élevé qui existerait entre les alvéoles et la pression barométrique ambiante au début d'une décompression rapide a amené à étudier un vêtement pressurisé.

Celui-ci a donc un double but, assurer l'isobarie respiratoire et autoriser la respiration en surpression à fort gradient d'une part, assurer un rapport de pression évitant la distension pulmonaire lors d'une décompression, d'autre part.

Etant donné l'obligation qu'à le pilote de s'équiper d'un pantalon anti-g pour l'exécution de sa mission, quelle que soit l'altitude atteinte, il a été décidé d'utiliser cet équipement pour réaliser la contrepression de l'abdomen et des membres inférieurs.

La protection des territoires supérieurs, est réalisée par un blouson pressurisé, les deux équipements étant asservis au régulateur. Enfin un casque étanche, lui aussi, assure la protection de la tête. Il comporte en outre, un étage respiratoire péri-facial qui remplace le masque traditionnel.

En utilisation normal l'équipement assure la protection anti-G et d'autre part la protection contre l'hypoxie. S'il y a perte rapide de la pressurisation cabine le pantalon anti-G n'obéit plus à la loi de la valve mais à la loi de surpression altimétrique du régulateur et se gonfle comme le blouson et le casque de façon à rétablir à toute altitude une pression de 18,6 KPa (2,65 psi), soit environ 40.000 ft.

Cet équipement en trois parties, permet un habillage rapide et un confort accru.

Les chances de victoires appartiendront au pilote opérant dans <u>les meilleures conditions de confort</u>. Au stress lié aux variations brutales de vitesse et de direction, à la haute altitude, à la tâche mentale élevée, nous devons nous garder d'ajouter les

contraintes liées à un siège inconfortable, à des boutons ou manettes inaccessibles, ou mal dessinées, à une cabine exigüe et mal climatisée.

Ce dernier point nous parait primordial.

Dans les avions de combat, dans le Mirage 2000, le volume de la cabine est bien faible en regard de la surface vitrée. La contrainte thermique due à la radiation en altitude peut y être très élevée et réaliser des points chauds insupportables. D'autant plus que le port d'un équipement important et du casque gêne considérablement les possibilités de thermolyse physiologique. La climatisation de l'avion doit donc être particulièrement soignée quitte à sacrifier quelques KPa dans la pressurisation de l'avion. Elle restera pourtant encore longtemps tributaire du refroidissement de l'électronique de bord dont la masse va en augmentant.

En conclusion, les missions dévolues au Mirage 2000, auront indubitablement des répercussions sur l'état physiologique du pilote et peut être aussi sur sa santé à long terme. Ce sont les accélérations intenses sans cesse changeantes en module et en direction qui représentent à nos yeux le facteur limitant actuel de l'adaptation de l'homme aux avions futurs.

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DISCUSSION

vonRestorff (FRG). You mentioned that the air conditioning should be able to guarantee a constant skin temperature of some 33 degrees C. Does this hold for all sorts of flight clothing?

Beck (UK). Strictly, yes, as this refers to the mean skin temperature (i.e., under the clothing). The quoted necessary range of cockpit temperatures, however, does not account for the additional insulative effects of multiple and/or impervious layers of clothing as in NBC clothing, assemblies, use of an immersion garment, etc.

Austin (USA). I heard reference in the French aircraft to a high altitude pressure suit for missions above 50,000 feet, I presume, but no reference in the other two. Does each of the aircraft have capability for a high altitude pressure suit?

Varin (FR). On the Mirage 2000 we have a pressure suit, not a fully-pressure suit, but what we tried to do with the 2000 is to have the capability of coming back down to 30,000 feet without any problem. In the old Mirage 3 we had the capability of flying one hour without pressure at very high altitude.

Beck (UK). A pressure suit could be used with the Tornado but its use is not now planned.

Ettinger (USA). A full pressure suit was flown for test purposes only in the YF-16. The production F-16 is not intended to be used operationally with a pressure suit.

Brictson (USA). For the author on the information transfer paper, at what stage of development are these missile launch envelope displays? Are they operationally available now, have they been experimentally evaluated?

Kulwicki (USA). On the F-16 and F-15 aircraft we have missile launch envelope displays operationally. The technique in this paper of providing this continuous engagement trend indicator is presently in advanced development and about to enter flight test phase. Yes, there are operational fire control displays for missile launch envelopes. We intend to improve them.

Thomas (USA). On the YF-16 you indicated three ranges, the R max, the R min and the R regardless of maneuver. The R max is dependent upon the aircraft target maneuvering. You showed that, is that correct?

Kulwicki (USA). Yes, in fact the way fire control system are mechanized, the fire control solutions assume nonmaneuvering targets. The exception is the F-15 aircraft as a so-called deterministic algorithm that holds the target g-level at release for a period of two seconds then reverts back to nonmaneuvering status.

Thomas (USA). In those three categories that you showed on the slide, the R max, is that a function of the target maneuvering or is that presuming no maneuvering?

Kulwicki (USA). Essentially no maneuvering.

Colin (FR). Why, having a 30 degree back angle seat on the F-16 all the slides and film show us a pilot seating straightway?

Varin (FR). Having flown the Mirage 2000 and the F-16, I can answer this question. The seat, inclined at 30 degrees or more is very attractive in regard to the load factor maintained by the pilot. And also it is very comfortable. But an aircraft, specially a fighter, is not done only for ferry flights, or acrobatics under heavy g. The pilot must shoot the target which is not always in steady flight. The pilot has to use head down and head up. He must see them and especially he has to use the complete (view field range) of the head up and he can't afford to be at 80cm or more of the HUD. Therefore, the pilot is taking the best place to use the whole symbology of the HUD. The mounted flight helmet can improve in a certain respect this problem and for short periods the pilot can use it, specially in combat but in that case he will not have all the information given in the HUD.

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14. Abstract

Any new system is no more effective than its human operators, whose sensory, muscular and cognitive capabilities it merely extends when responding to mission and environmental stress.

The purpose of this meeting session was to understand the operational characteristics of the new high-performance aircraft to be shortly introduced into the NATO Forces in relationship to the operator's physiological, cognitive, psychomotor and perceptual capabilities.

For the first time at an AMP meeting, pilots, engineers and aviation medicine specialists convened together to discuss relationships between man and machine in order to identify any biotechnology research deficiencies and establish appropriate selection, training and assignment criteria for future high-performance aircraft.

Papers presented at the Aerospace Medical Panel's Specialists' Meeting held in Lisbon, Portugal, 22–26 October 1979.

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